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INVESTIGATION OF MEASURING LARGE THREADS WITH GAGES OF LIGHT-WEIGHT MATERIAL. PHASE II

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Watervliet, New York

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An experimental investigation of the dimensional stability of composite thread gages was undertaken. Interest was focused on the effect of composite material, filament tension, manufacturing process (wet & pre-preg material), molding, filament-volume ratio, internal geometry (plain diameter ring, "V" thread and acme thread gages) and thickness, at two or more levels. This phase concentrates on the filament winding process rather than the vacuum molding process. It can be concluded from this limited study that curing temperature is the most

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Block 20 ABSTRACT

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INVESTIGATION OF MEASURING LARGE THREADS
WITH GAGES OF LIGHT-WEIGHT MATERIAL
(PHASE II)

BY

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OCTOBER 1974

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IC

MATERIALS TESTING TECHNOLOGY PROGRAM (AMS 4931)

Report No. : WVT-QA-7404

Title: Investigation of Measuring Large Threads With Gages of Lightweight Material (PHASE II)

THIS PROJECT HAS BEEN ACCOMPLISHED AS PART OF THE US ARMY MATERIALS TESTING TECHNOLOGY PROGRAM, WHICH HAS FOR ITS OBJECTIVE THE TIMELY ESTABLISHMENT OF TESTING TECHNIQUES, PROCEDURES OR PROTOTYPE EQUIPMENT (IN MECHANICAL, CHEMICAL, OR NONDESTRUCTIVE TESTING) TO INSURE EFFICIENT INSPECTION METHODS FOR MATERIAL/MATERIAL PROCURED OR MAINTAINED BY AMC.

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INVESTIGATION OF MEASURING LARGE THREADS WITH GAGES OF LIGHTWEIGHT MATERIAL (PHASE II)

ABSTRACT

An experimental investigation of the dimensional stability of composite thread gages was undertaken. Interest was focused on the effect of composite material, filament tension, manufacturing process (wet & pre-preg material), molding, filament-volume ratio, internal geometry (plain diameter ring, "V" thread and acme thread gages) and thickness, at two or more levels. This phase concentrates on the filament winding process rather than the vacuum molding process. It can be concluded from this limited study that curing temperature is the most important parameter in obtaining dimensional stability of the composite gages. Tension of winding and thickness of the samples played a secondary role in achieving dimensional stability. Due to the limited investigation of vacuum molding, no definitive conclusions on dimensional stability were reached.

CROSS REFERENCE DATA

Measuring Cannon Threads
Fiber-reinforced Composites
Composite Thread Gages
Dimensional Stability

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I. INTRODUCTION

Phase I of project "Investigation of Measuring Large Threads with Gages of Lightweight Material" was completed Sept 1972 (Ref-Technical Report WVT-QA-7301). The results of work performed during phase I indicated that fiber-reinforced composite materials had a potential of being a substitute for steel in the design of lightweight large thread gages that will effectively measure the thread characteristics with a minimum of time and effort. This conclusion was based on the following project results:

A. Wear was nearly comparable to steel.

B. Costs were estimated to be 50% less than steel.

C. Weight reductions of 80% were realized.

D. Lead time for thread gage could be reduced from 8 to 12 months to one or two weeks.

E. Introduced the possibility of throw-away gages for cannon in and out of production which would eliminate storage and surveillance costs since a new gage could be made in a matter of days.

Along with the above favorable results, phase I testing also revealed that the stability characteristics of the composite material used was less than desirable. However, it was felt at the time since a required stability was theoretically obtainable, additional studies and testing of various composites would yield satisfactory results. Therefore it was recommended that further studies and testing of composite materials be undertaken to obtain desired material properties for use in the

design of large thread gages. Phase II of this work, funded by an FY73 MTT project, will now be described and analyzed. Moreover it includes consideration of composite materials in the use of other types of inspection gages as well as other items where weight, cost and procurement time is a factor.

This report describes the experimental study of the dimensional stability of composite thread gages with interest focused on the effect of filament tension, manufacturing process (wet & pre-preg material), molding, filament-volume ratio, internal geometry (plain diameter ring, "V" thread and acme thread gages), and thickness at two or more levels.

II. FABRICATION

Three basic composite configurations, plain diameter rings, V-thread and acme thread were fabricated by a filament winding process. A molding process was also investigated. The following outlines the fabrication of the various samples:

A. Filament Winding Process:

The filament winding machine, FIG. 1, used in the fabrication is electronically controlled, programable, servo-driven unit with a high degree of winding flexibility. The fabrication technique consists of three parts: (1) winding hoop layers on a mandrel to a desired thickness, (2) curing of the layers at controlled temperature and (3) separating the cured composite sample from the mandrel. The matrix used in the construction of the wet-wound gages was an epoxy mixture composed of 50% "EPON 828" manufactured by the Shell Chemical Corp. and 50% "VERSAMID 140" developed commercially by General Mills Inc. The reinforcement used in the wet-wound was 20 end "S-GLASS" (901) manufactured by the Ferro Corp. For the samples that were wound with pre-preg material, the fiberglass was 20 end "E-Glass" pre-impregnated with an epoxy/anhydride/amino resin system, manufactured by U.S. Polymeric, Inc.

1. Plain diameter ring gages:

In all, ten composite plain diameter ring gages were manufactured on a master plug of 3.6872 inch diameter with various tensions of winding, thicknesses and curing temperatures. In FIG. 2

is a picture of samples2(T1), 4 (T2), 6 (T3) and 8 (T4). Table I gives a summary of the samples and the conditions used to manufacture them.

Sample No.	Tension of Filament (lbs)	Thickness*(Inches)	Curing
1	7	1	200°F for 4 hrs.
2	7	1	70°F for 48 hrs.
3	7	.5	200°F for 4 hrs.
4	7	.5	70°F for 48 hrs.
5	1	.5	200°F for 4 hrs.
6, 9, 10	1	.5	70°F for 48 hrs.
7	1	1	200°F for 4 hrs.
8	1	1	70°F for 48 hrs.

TABLE I. Manufacturing Parameters

2. Acme thread gages (complete thread ends)**

There was a total of four composite gages wound on master acme-thread plug 7244328, serial number V53-7897. Two of the four samples are pictorially shown in FIG. 3 (two samples on left). The dimensions on the master plug are listed in Appendix A. Two of these gages (composite samples 11, 12) were wound with 20-end pre-impregnated "S-

* The thickness refers to the build-up of the reinforcement (glass) and matrix above the top of the threads or in the case of the plain diameter ring above the plug nominal size.

** Complete thread end is when the feather edge of a thread that remains after grinding at each end of a thread plug is removed back to a point where a complete thread cross-section begins, commonly referred to as truncated end.

Glass" while the other two were wet wound (composite samples 13, 14) using "S-Glass" (901) "EPON 828" and "VERSAMID 140" resin. The two pre-preg wound samples 11, 12 were wound with a filament tension of seven pounds and cured to 220°F for two hours and oven-cured at 350°F for two hours, then slowly cooled to room temperature. The two wet wound samples 13, 14 were wound with a filament tension of one pound and cured at room temperature for forty eight hours. All samples were approximately one inch thick.

3. "V"-thread gages (incomplete thread ends):*

Two gages (composite samples 15, 16) of this configuration were wound on master V-thread plug 3.250-4UNC-1A serial number 5220-751-5177, see FIG. 4. A data sheet on this master V-plug can be found in Appendix A. The two gages were wet-wound with a filament tension of one pound, made one inch thick and cured at room temperature, 70°F, for forty-eight hours.

4. Acme thread gages (incomplete thread ends):*

One gage (composite sample 17) of this configuration was wound using master acme-thread plug 7244833, serial number V52-20075. This gage is pictorially shown in FIG. 3 (one on right). The dimensions of this master plug is listed in Appendix A. This gage was wound under the same conditions as composite samples 15, 16.

B. Molding Process:

Three acme thread gages were vacuum molded (FIGS. 5 and 6)

---

* Incomplete thread ends are ones in which the feather edge is not removed.

with complete thread ends. The following is an outline of the manufacturing process.

1. Aluminum fiber gage:

This gage (composite sample 18) was made by packing .005" x .005" x .125" aluminum fibers into a vertical lucite mold with the use of a vacuum. Figure 7 pictorially displays this molded gage. After packing was accomplished, resin consisting of a 1:1 mixture of "EPON 828" and an anhydride curing agent was drawn through the fibers with the aid of a vacuum. The sample was room temperature cured.

2. Glass fiber gage:

This gage (composite sample 19) was fabricated by hand packing 1/4 inch long "S-Glass" fibers at one open mold face. The resin, 1:1 mixture of "EPON 828" and an anhydride curing agent, was then pulled through the mold by the application of a vacuum on the bottom of the mold. The sample was then room temperature cured.

3. Aluminum glass fiber gage:

Unlike the previous two molded samples 18 and 19, this gage (composite sample 20) was made in two steps. First a thin coat, approximately 1/8 inch, of epoxy, 1:1 mixture of "EPON 828" and an anhydride curing agent, and aluminum fibers were placed in the thread area (for wear resistance) and cured at an elevated temperature of 200°F. The second step is identical to the operation performed on the glass-fiber gage, composite sample 19.

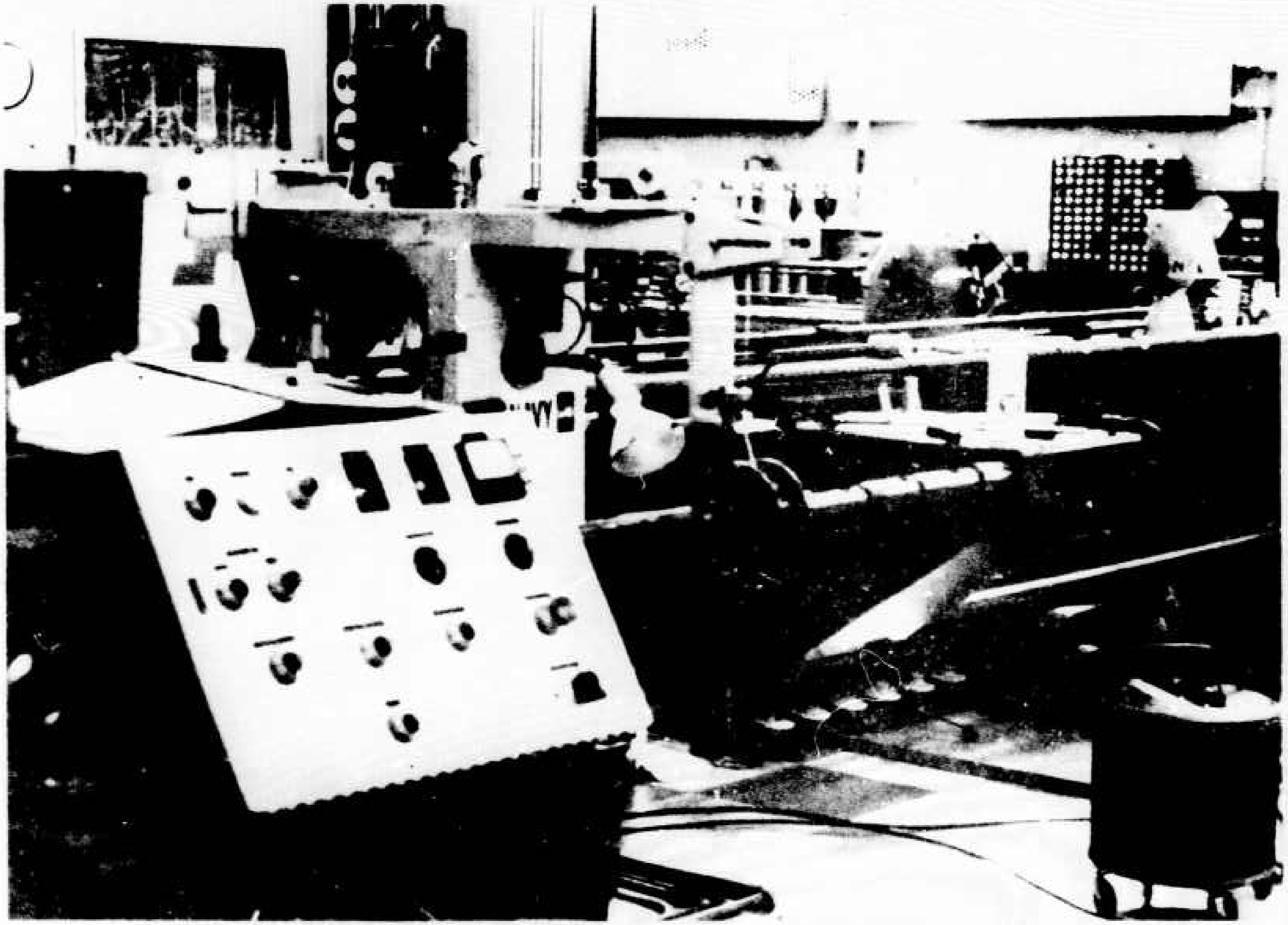


Figure 1 Filament Winding Machine

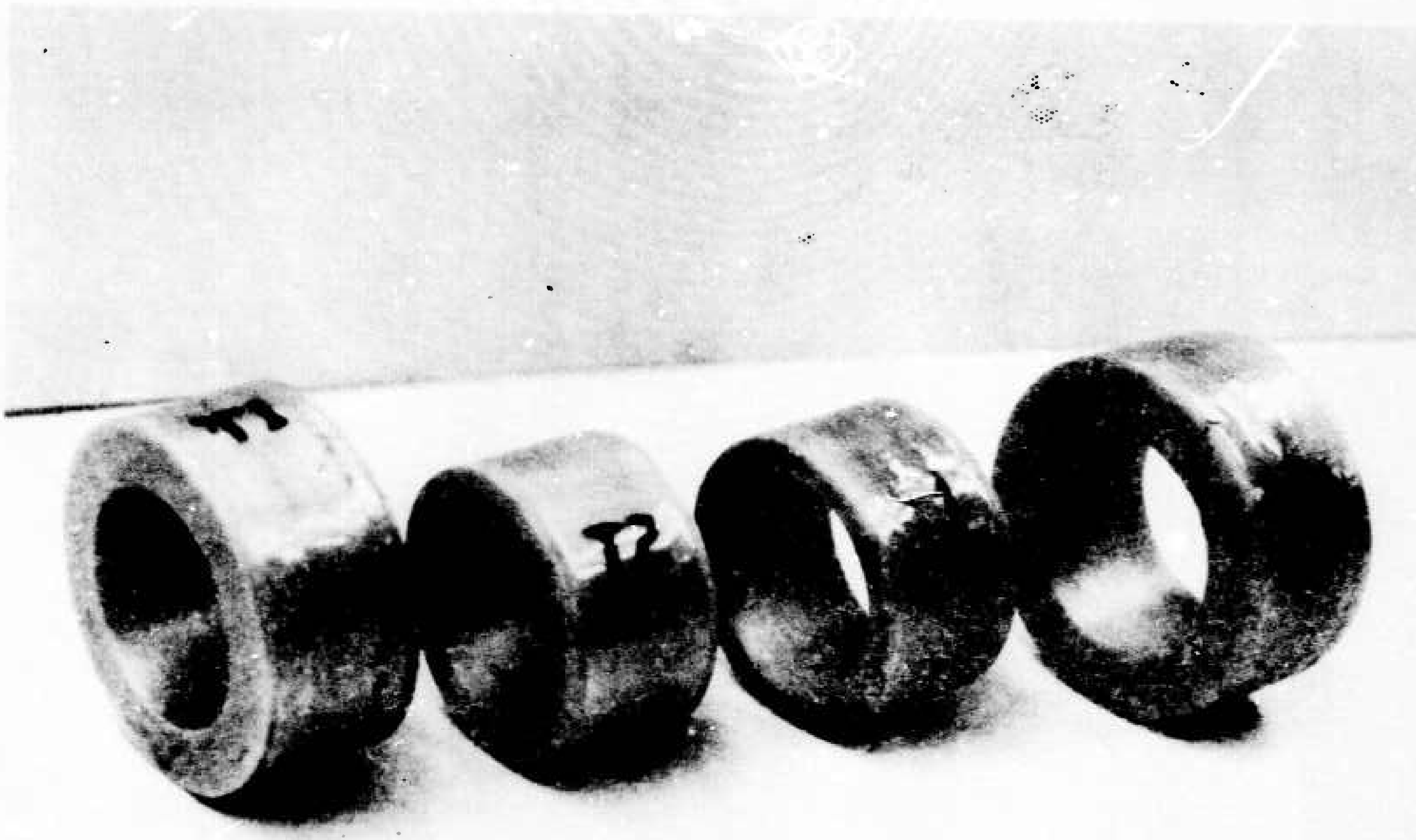


Figure 2 Pictorial View of Samples 2,4,6 and 8

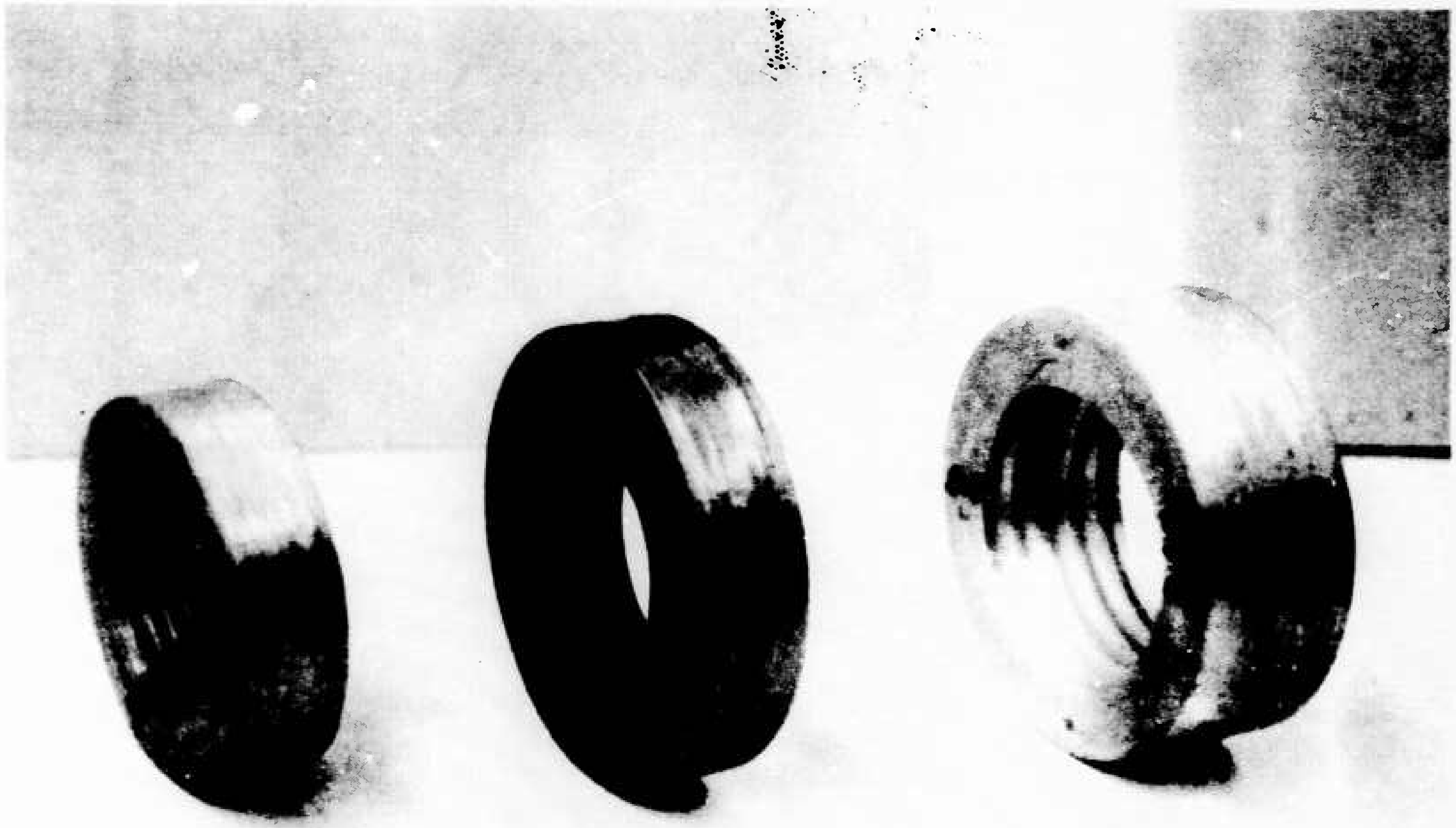


Figure 3 Pictorial of Wound Acme-Thread Gages (Samples 11, 13 and 17)

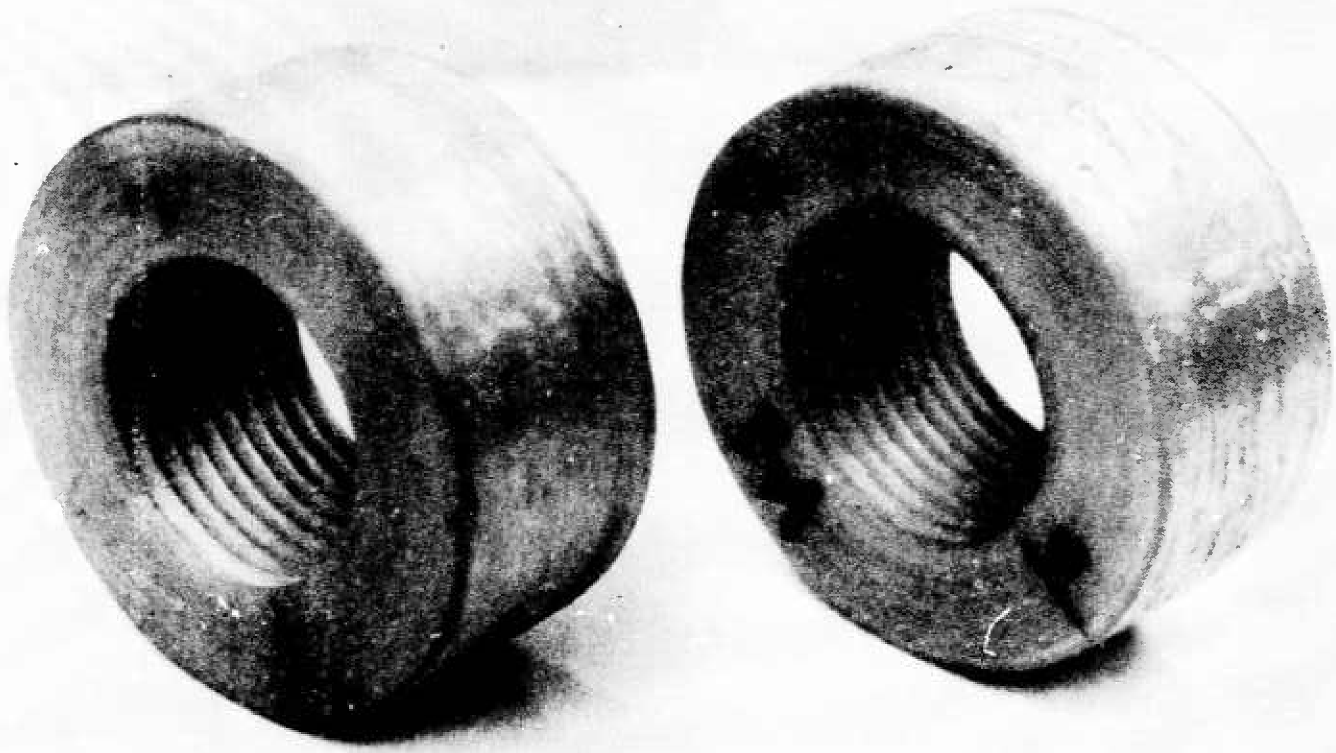


Figure 4 Pictorial of Wound V-Thread Gages (Samples 15 and 16)

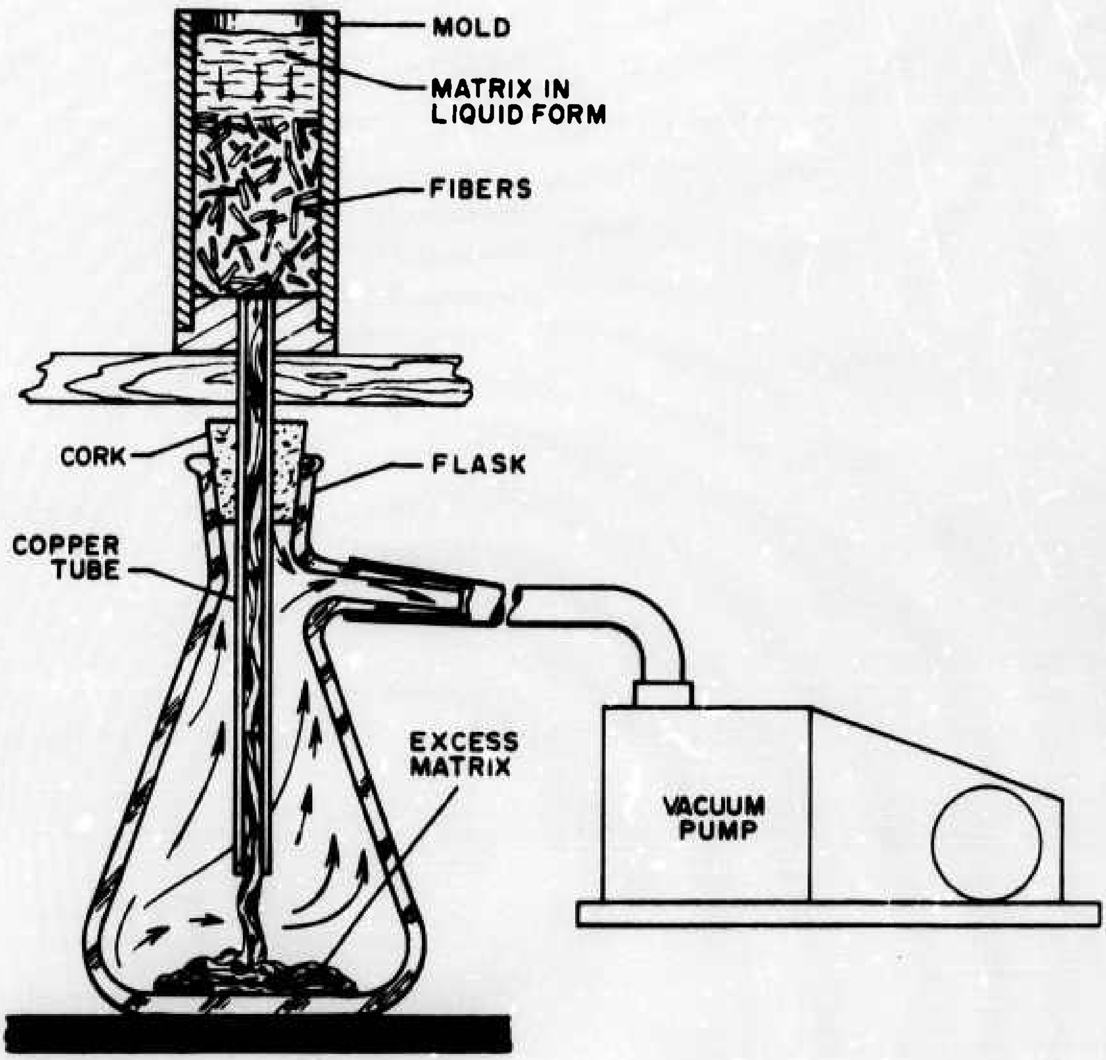


Figure 5 Vacuum Molding Equipment

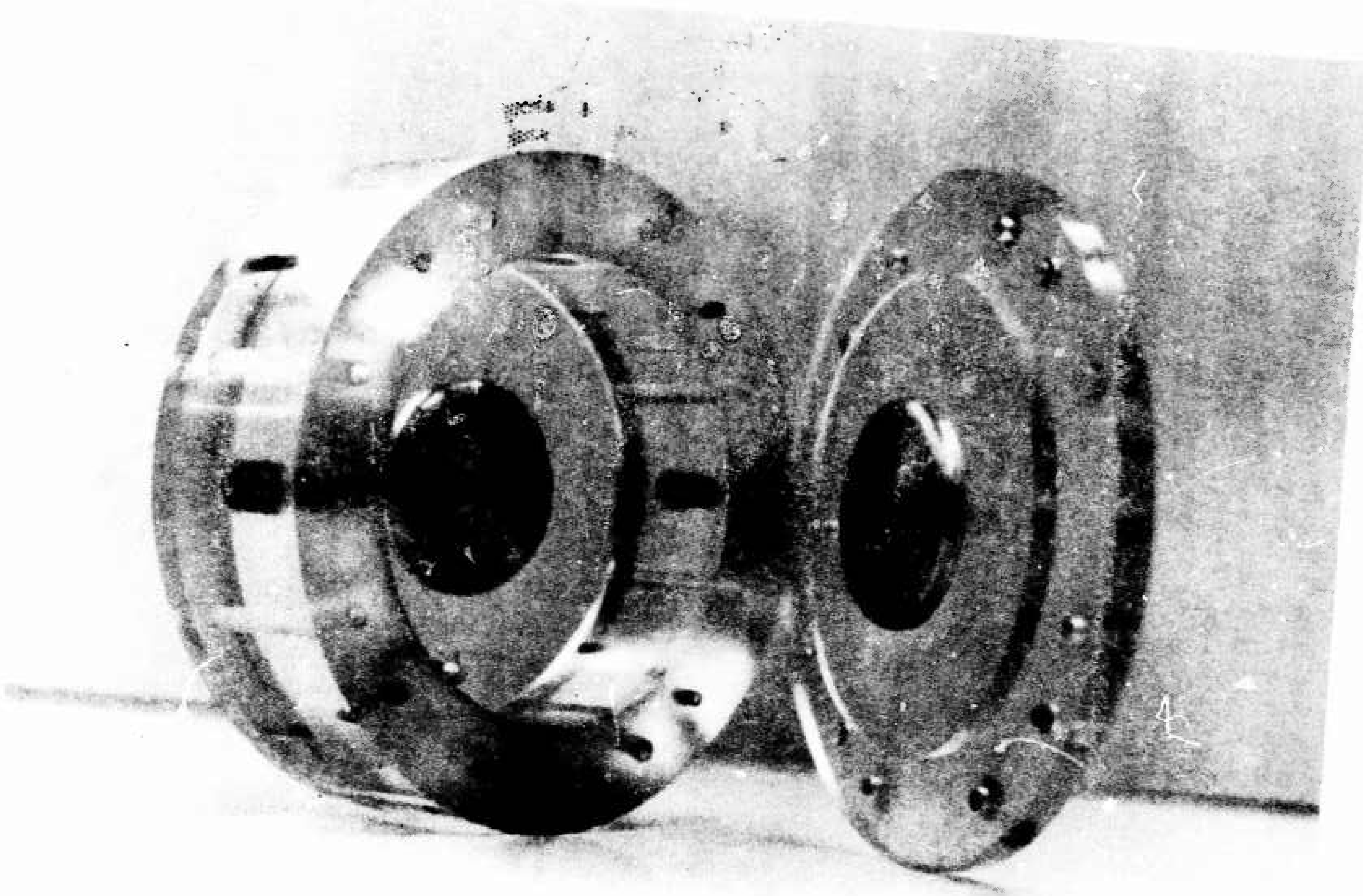


Figure 6   Pictorial of Vacuum Casting Mold

Figure 7 Pictorial of Molded Acme-Thread Gage (Sample 18)

III. TESTING

This phase of the report concentrates on determining the dimensional stability (diametrical variation, bore taper and roundness) of lightweight composite gages subject to the varying fabrication parameters (winding tension, gage thickness, curing temperature and extreme operating temperature conditions). This testing demonstrates, on a limited sampling, that the fabrication technique plays an important role in the dimensional stability of the gage.

The following outlines, in detail, the test plan of the Lightweight Composite Thread Gage Program:

A. Dimensional Stability Test of Plain Diameter Ring Gages:

The purpose of this test is to determine the effect tension of winding, thickness and curing temperature as well as shelf life has on the dimensional stability of the composite gage. Results are given in Appendix B.

1. Gages to be tested: Composite samples 1 through 8

2. Simulation:

a. Dimensional stability after initial curing period. This reading is designated as 1st-Day.

b. Dimensional stability after setting for four days, after initial winding, at room temperature, 70°F. This reading is designated as 4th-Day.

c. Dimensional stability after setting for seven days, after initial winding, at room temperature, 70°F. This reading is designated as 7th-Day.

3. Measurements and instrumentation:

Measurement*	Instrumentation
a. Variation in diameter: Readings are taken at 0, 30, ... 150 angular degrees at the following distances from the top face of the gage: (1) 1/8 inch (top reading) (2) 1 1/4 inch (middle reading) (3) 2 3/8 inch (bottom reading)	a. Boice #5 Dial Bore Gage, Serial Number 8772805, Boice #25 Bore Gage Setmaster, Serial Number V-66-1625, Granite Surface Plate 18" x 24", Serial Number VI-55-771
b. Bore taper: Readings are taken every 30 angular degrees at the following distances from the top face of the gage: (1) 1/8 inch (top reading) (2) 1 1/4 inch (middle reading) (3) 2 3/8 inch (bottom reading)	b. Federal Testmaster Dial Indicator (.001"), Serial Number VI-67-1275, Check Master Height Gage, Serial Number VI-57-583, Cast Iron Angle Plate 6" x 8" x 10", Serial Number S-62-887, Granite Surface Plate 18° x 24", Serial Number VI-55-771

* Figure 8 pictorially shows the location that readings are taken from.

c. Roundness: Readings are taken continuously for 360 angular degrees at the following distances from the top face of the gage:

(1) 1/8 inch (top reading)

(2) 1 1/4 inch (middle reading)

(3) 2 3/8 inch (bottom reading)

c. Taly Rond*, Serial Number VI-57-523

B. Reproducibility Test:

The purpose of this test is to determine the dimensional reproducibility of fabricating three composite gages using the same tension of winding, thickness and curing temperature. Results are presented in Appendix C and in Figures 19, 20 and 21

1. Gages to be tested: Composite samples 6, 9 and 10.

2. Simulation: Same as A2a and A2c.

3. Measurements and instrumentation: Same as A3a and A3b.

C. Elevated Temperature Tests:

The purpose of this test is to determine the effect exposure to elevated temperatures, 110°F, has on the dimensional stability of the composite samples. Results are presented in Tables II through V and Appendix D.

* Figure 9 pictorially shows this piece of equipment.

1. Gages to be tested: Composite samples 4 and 6.

2. Simulation: Composite samples are placed in an oven, at a temperature of 110°F, for one hour.

3. Measurement and instrumentation:

Measurement	Instrumentation
a. Same as A3a	a. Same as A3a
b. Variation in width: Readings are taken every 90 angular degrees	b. 2-3" Micrometer, Serial Number VI-60-122

4. Implementation:

In order to determine the effect of the sample being subjected to an atmosphere of elevated temperature, the sample is placed in an oven at a constant temperature of 110°F. Measurements are taken before the sample is placed in the oven (ambient temperature) and then at twenty minute intervals for one hour. The final ambient temperature reading is taken twenty hours after being removed from the oven. This complete procedure is duplicated two weeks after initially subjecting the sample to an elevated temperature.

D. Dimensional Stability Test of Acme Thread and V-Thread Gages:

The purpose of this test is to determine dimensional stability (pitch or lead, major and minor diameter and flank angle) of composite thread gages. Results are presented in Tables VI through X.

1. Gages to be tested: Filament wound composite samples 11 through 17 and molded samples 18, 19, and 20.

2. Simulation:

a. Samples 11 and 12 - Dimensional stability 1st day after initial curing, 4 days later.

b. Samples 13 and 14 - Dimensional stability after initial curing.

c. Samples 15 and 16 - Dimensional stability 1st day after initial curing, 5 days later, 60 days later.

d. Sample 17 - Dimensional stability 1st day after initial curing, 60 days later.

3. Measurements and instrumentation:

Measurement	
a. "V" thread (filament wound)	
1. Pitch diameter: Readings are taken at horizontal and vertical center lines.	1. Precision Balls .15625DIA Gage Blocks-Serial Numbers VI-59-102 and VI-57 557, Height Stand 18" Serial Number VI-57-557, .00005 Indicator, Serial Number VI-67-1257
2. Pitch and flank angle: Readings are taken at bottom vertical center line.	2. Precision "Perma-Stone" Casts of Third Profile, 14" J and L Optical Comparator* Serial Number VI-67-846

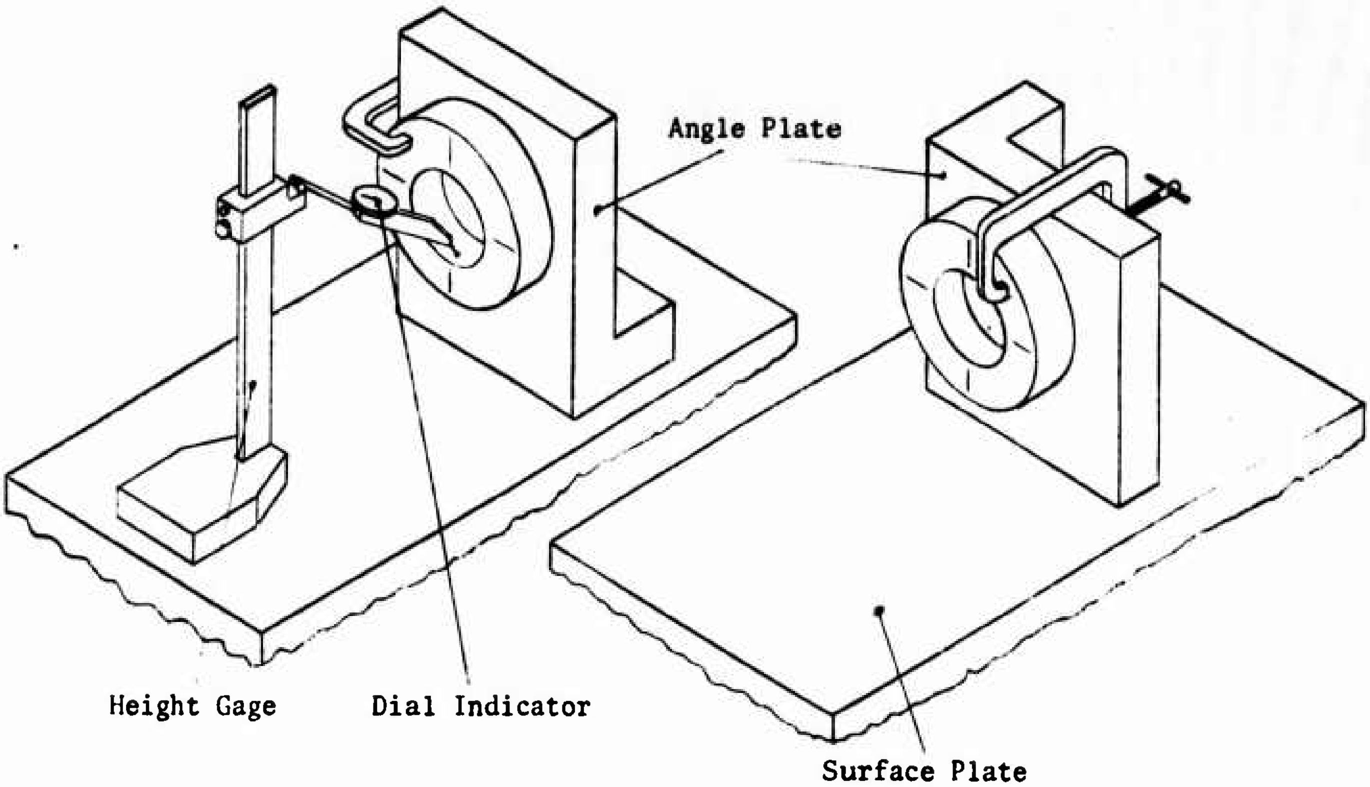
* Equipment is shown in FIG. 10.

b. Acme threads (filament wound)

1. Major diameter and minor diameter: Readings are taken at horizontal and vertical center lines at three depths, top, middle and bottom.	1. Gage Blocks - Serial Number VI-59-102, Height Stand, S Serial Number VI-57-557, Indicator .00005 Serial Number VI-67-1257, Surface Plate Serial Number VI-55-784
2. Same as D3a2 Acme threads (molded)	2. Same as D3a2

Testing was not performed due to problem of voids in threads.

(See discussion of results-Molding Process)



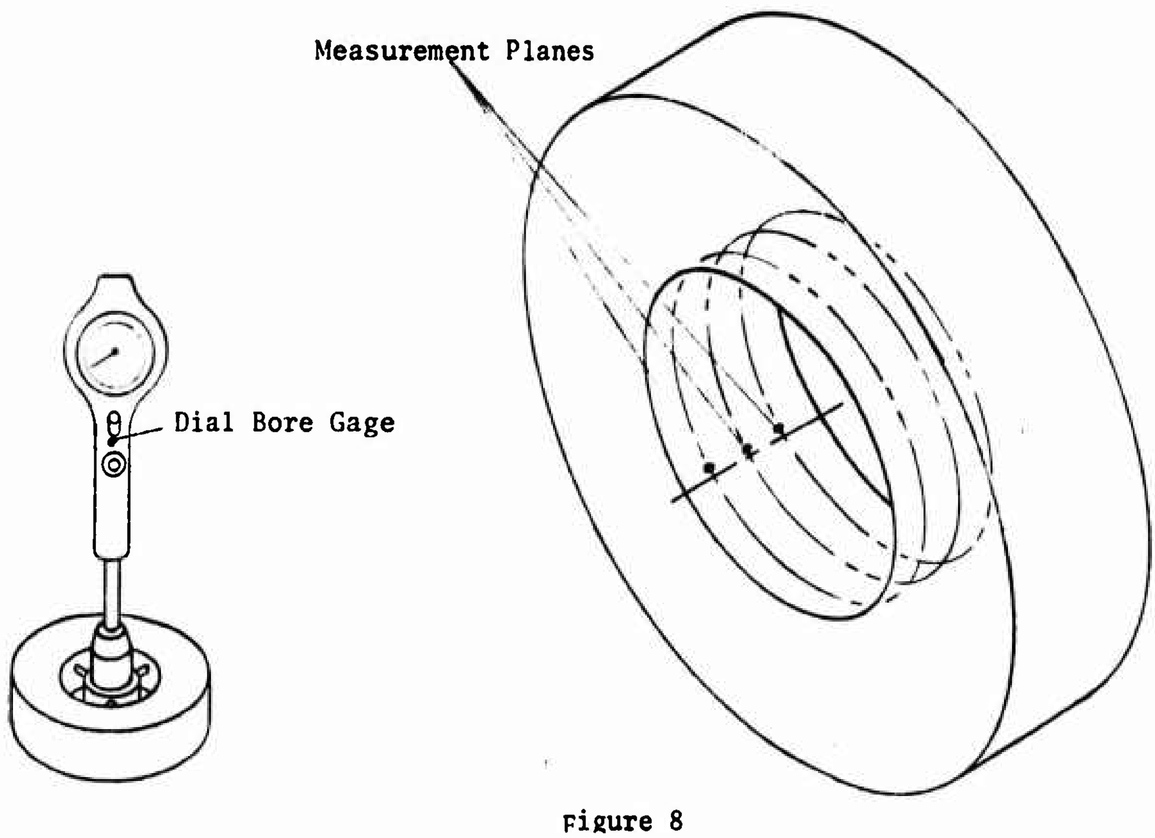


Figure 8

Inspection Method for Checking Diameter and Bore Taper of Samples 1 thru 8

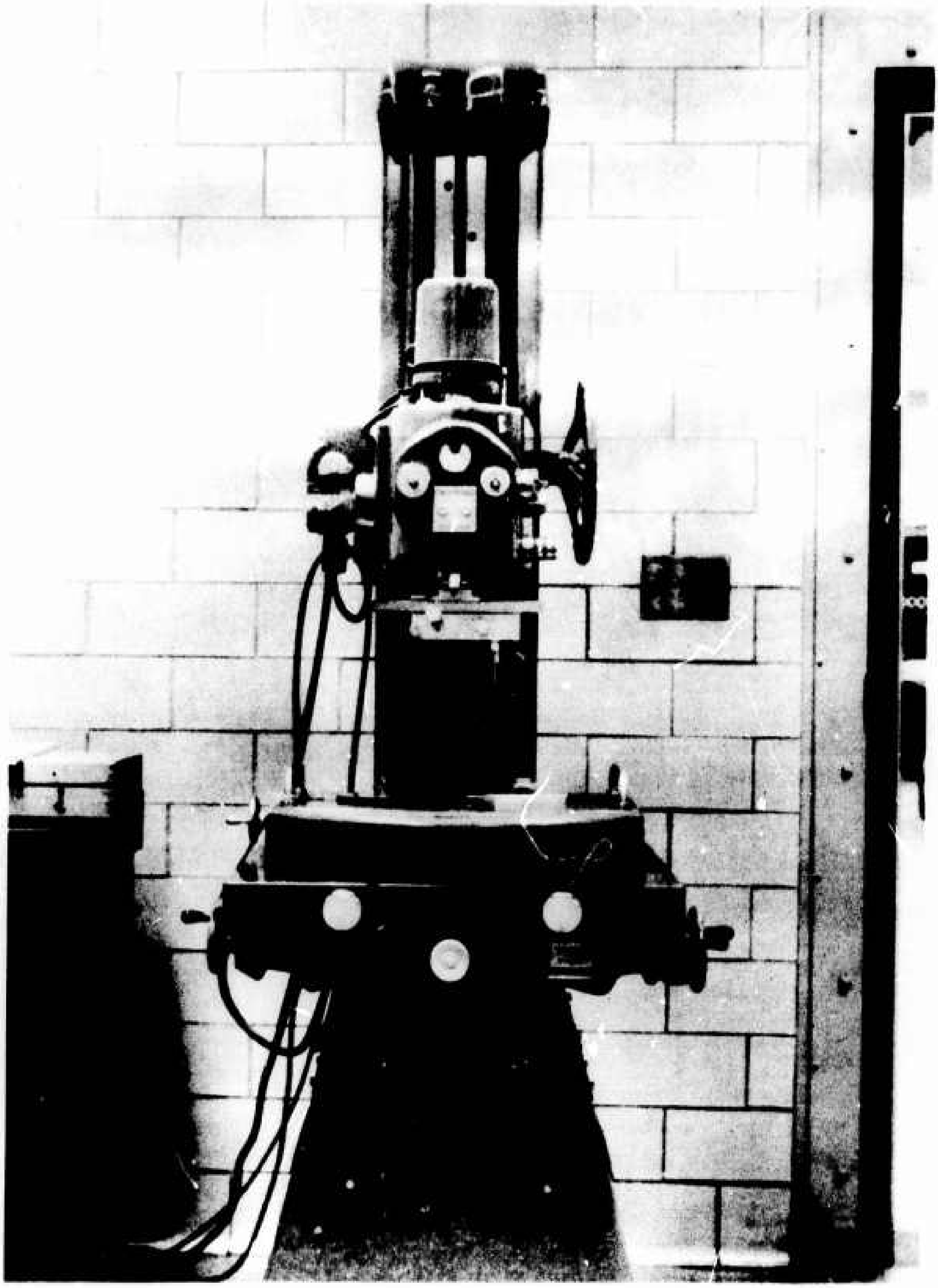


Figure 9 Taly Rond Used to Check Roundness of Samples 1 thru 8

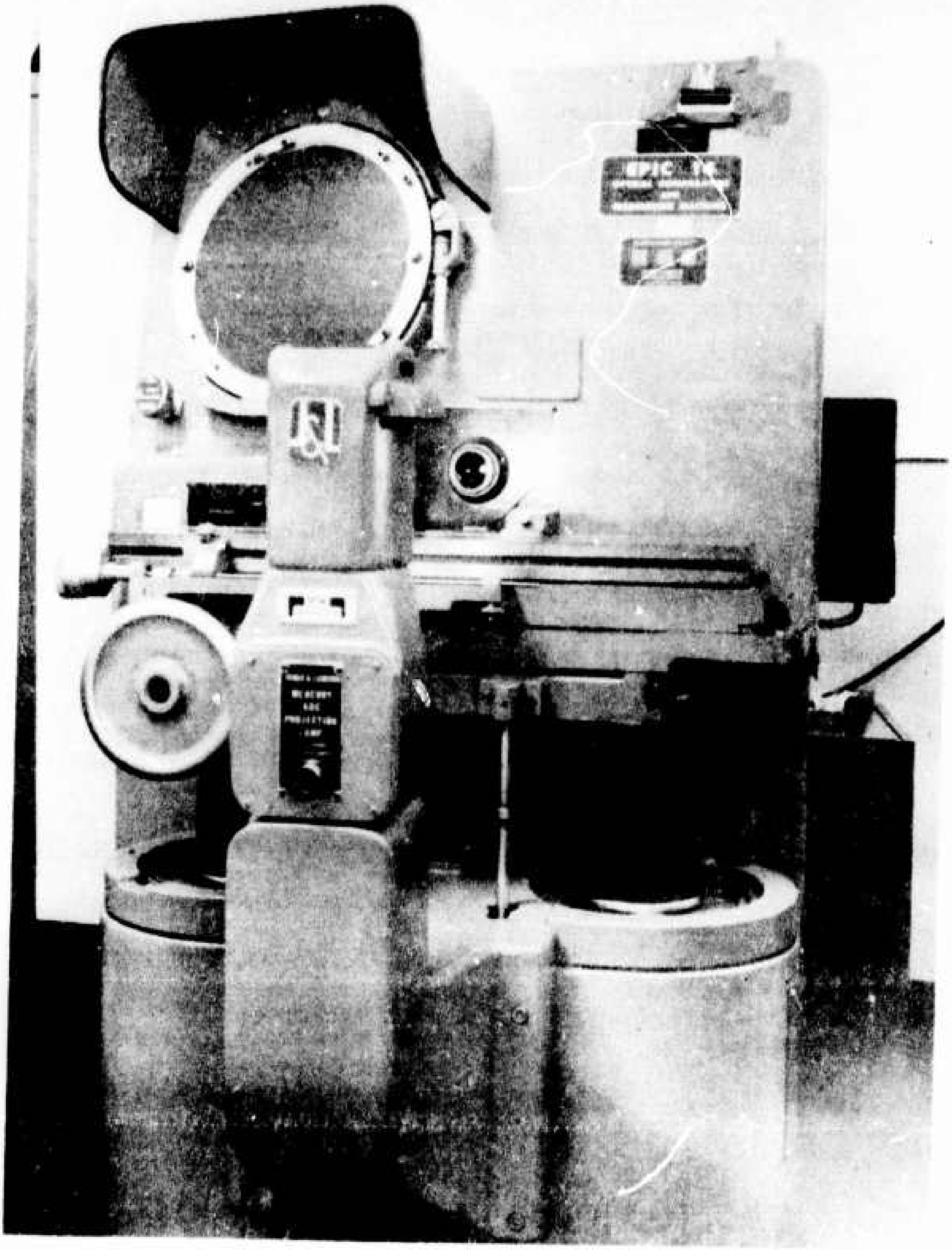


Figure 10 J and L Optical Comparator Used to Check Pitch and Flank Angles of Samples 11 thru 17

IV. DISCUSSION OF RESULTS

A. Filament Winding Process:

1. Dimensional stability test of plain diameter ring gages:

The dimensional stability test on the lightweight plain diameter ring gages is depicted in Appendix B. Three different measurements were taken; variation in diameter, bore taper and roundness in order to establish the dimensional stability of the composite samples.

Figures 11 and 12 depict the variation in diameter of the best and worst composite sample respectively. It should be pointed out that it is more important to consider the variation in diameter from position to position (top, middle, bottom and 0°, 30° ..., 180° angular degrees) than to consider the variation from the nominal size. If the expansion is uniform, no variation from position to position, an under sized master gage could be fabricated to compensate for the expansion in order to achieve the desired dimension. There are two fabrication parameters that differ, namely tension of winding and curing temperature. The thickness does not seem to be a contributing factor in these measurements. Sample 5 shows a large variation in the diameter readings because of low tension, one pound, results in a high concentration of resin which has a relatively high coefficient of thermal expansion, as compared to that of steel, and consequently upon curing the sample at 200°F, the sample expands a couple of thousands of an inch. It should be pointed out that between the 4th Day readings and the 7th Day

readings, sample number 4 expands uniformly by approximately .0002 inches.

In Figures 13a, b and 14a, b the variation in bore taper is shown for the best and the worst composite samples respectively. The only fabrication parameter which is different is the curing temperature. The thickness and tension of winding does not seem to be a contributing factor. The elevated curing temperature, 200°F, of sample 5 causes the resin to expand resulting in a large variation in bore taper. There does not seem to be an appreciable difference between the 1st, 4th and 7th Day readings.

The final measurements taken in this phase of testing, was that of roundness. Figures 15, 16 and 17 depict the samples that were the closest to true roundness while Figure 18 depicts the sample that deviates the most from true roundness. Samples 4, 6 and 8 were wound with different filament tension and thickness but were all cured at room temperature. On the other hand, sample 5 was cured at an elevated temperature. It is clear that the elevated temperature cure caused the sample to distort. Some samples do not have 4th and 7th Day readings. The reason for this is that the Taly-Rond machine broke down in the later part of the testing and was not repaired in time.

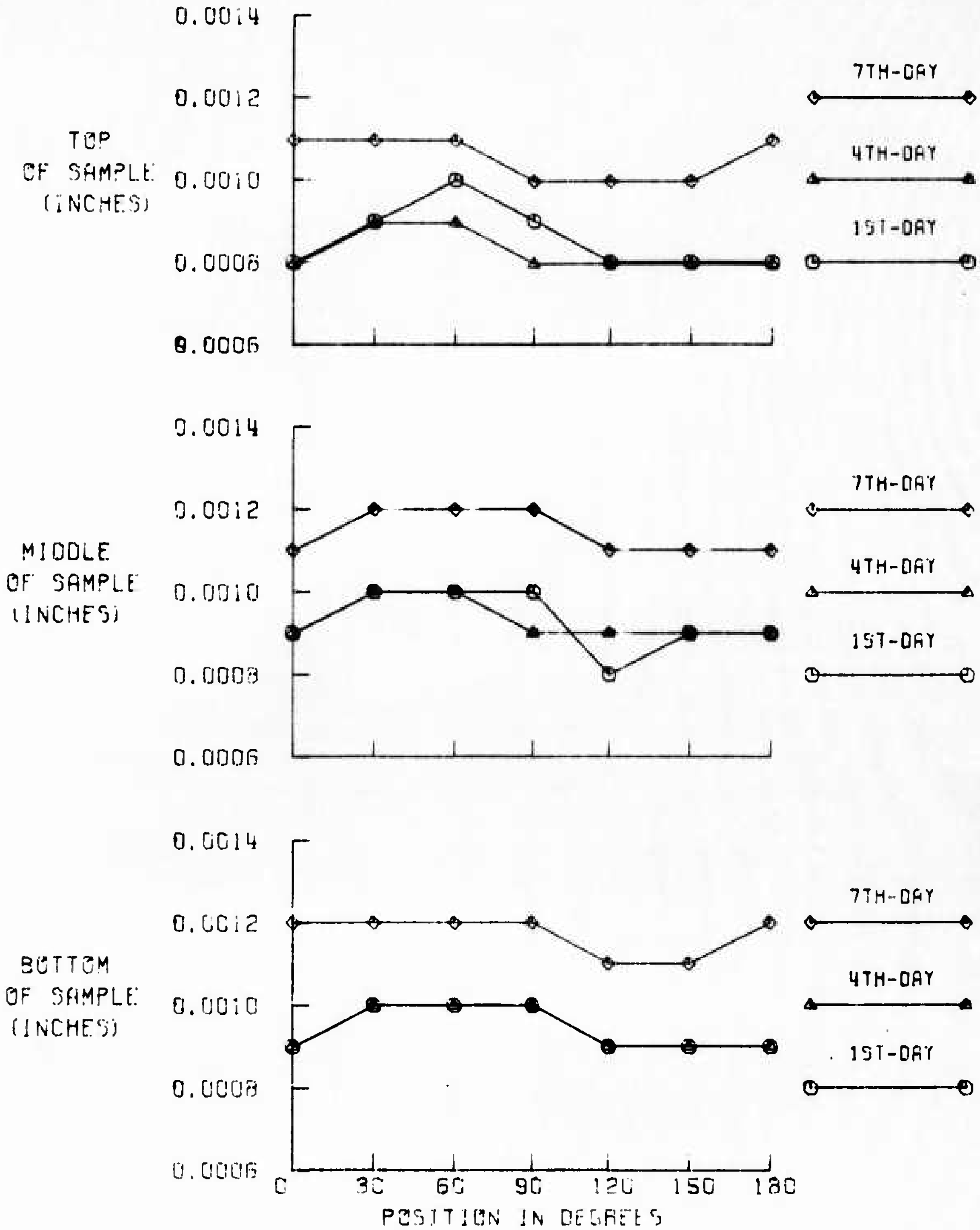


FIG. 11: DIAMETRICAL VARIATION FROM THE NOMINAL SIZE OF 3.6872 INCHES FOR SAMPLE NUMBER 4 WOUND WITH 7 POUNDS TENSION, 1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

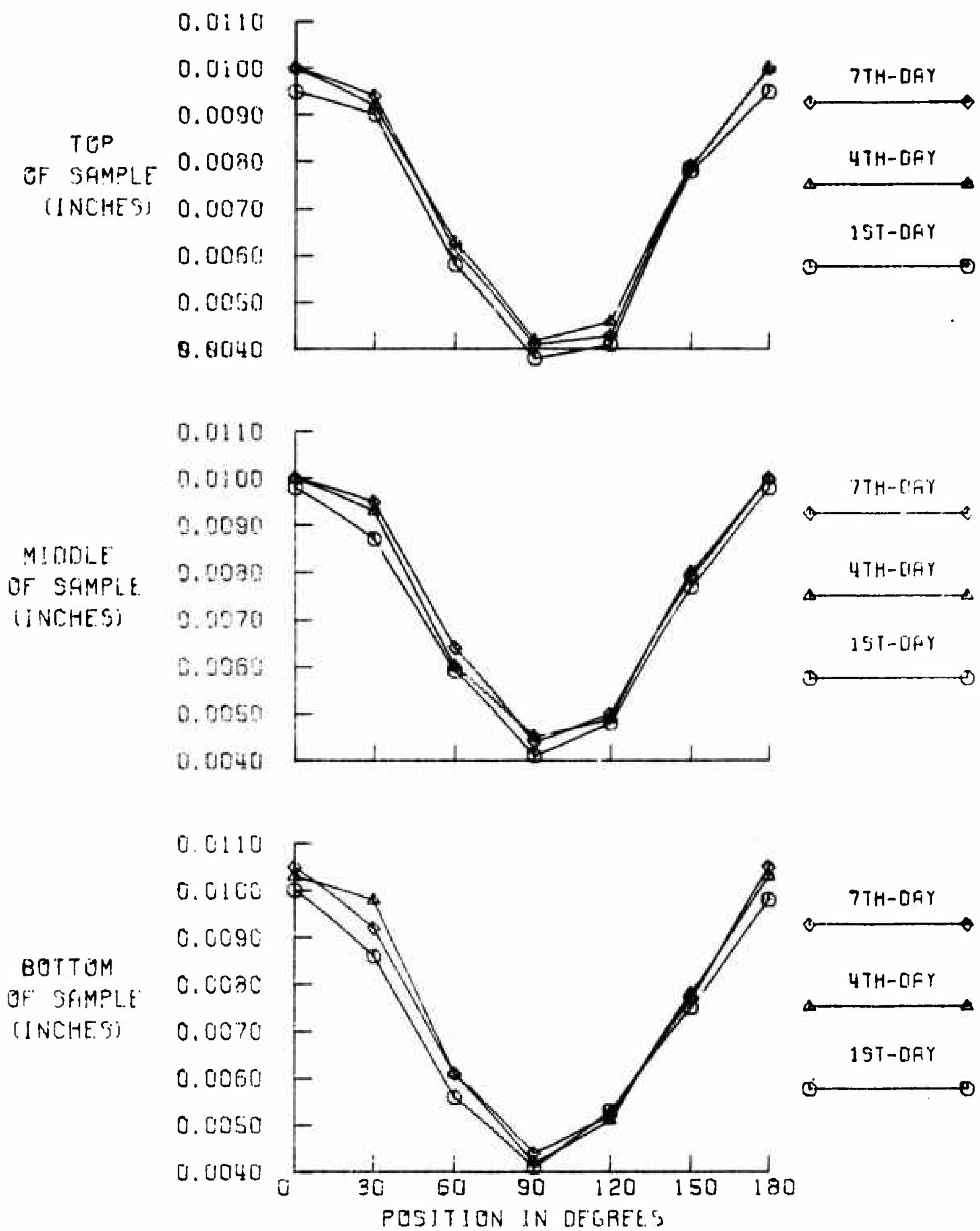


FIG. 12 : DIAMETRICAL VARIATION FROM THE NOMINAL SIZE OF 3.6872 INCHES FOR SAMPLE NUMBER 5 WOUND WITH 1 POUND TENSION. 1/2-INCH THICK AND CURED AT 200F FOR 4 HOURS

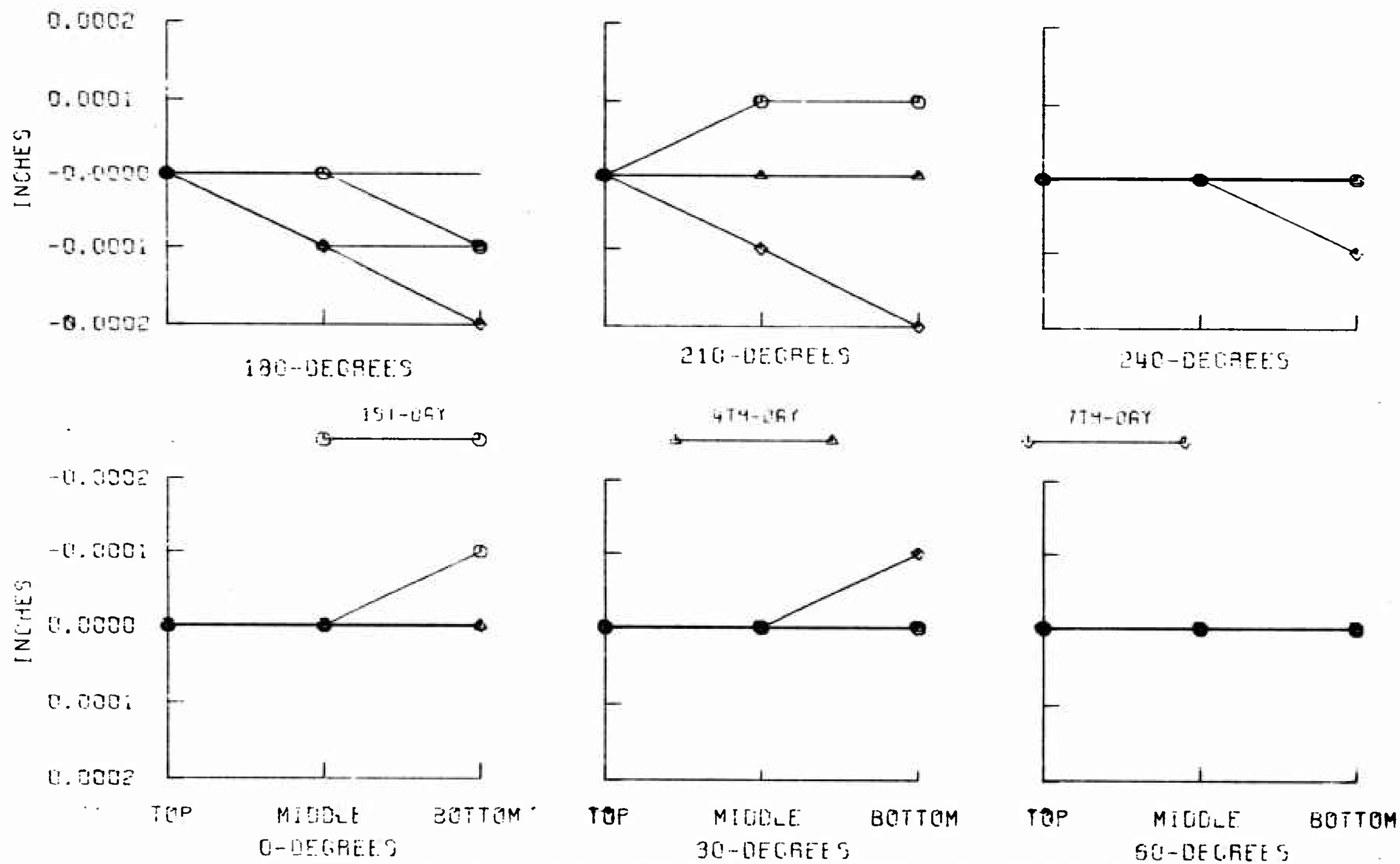


FIG. 13 a: BORE TAPER FOR SAMPLE NUMBER 6 WOUND WITH 1 POUND TENSION, 1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

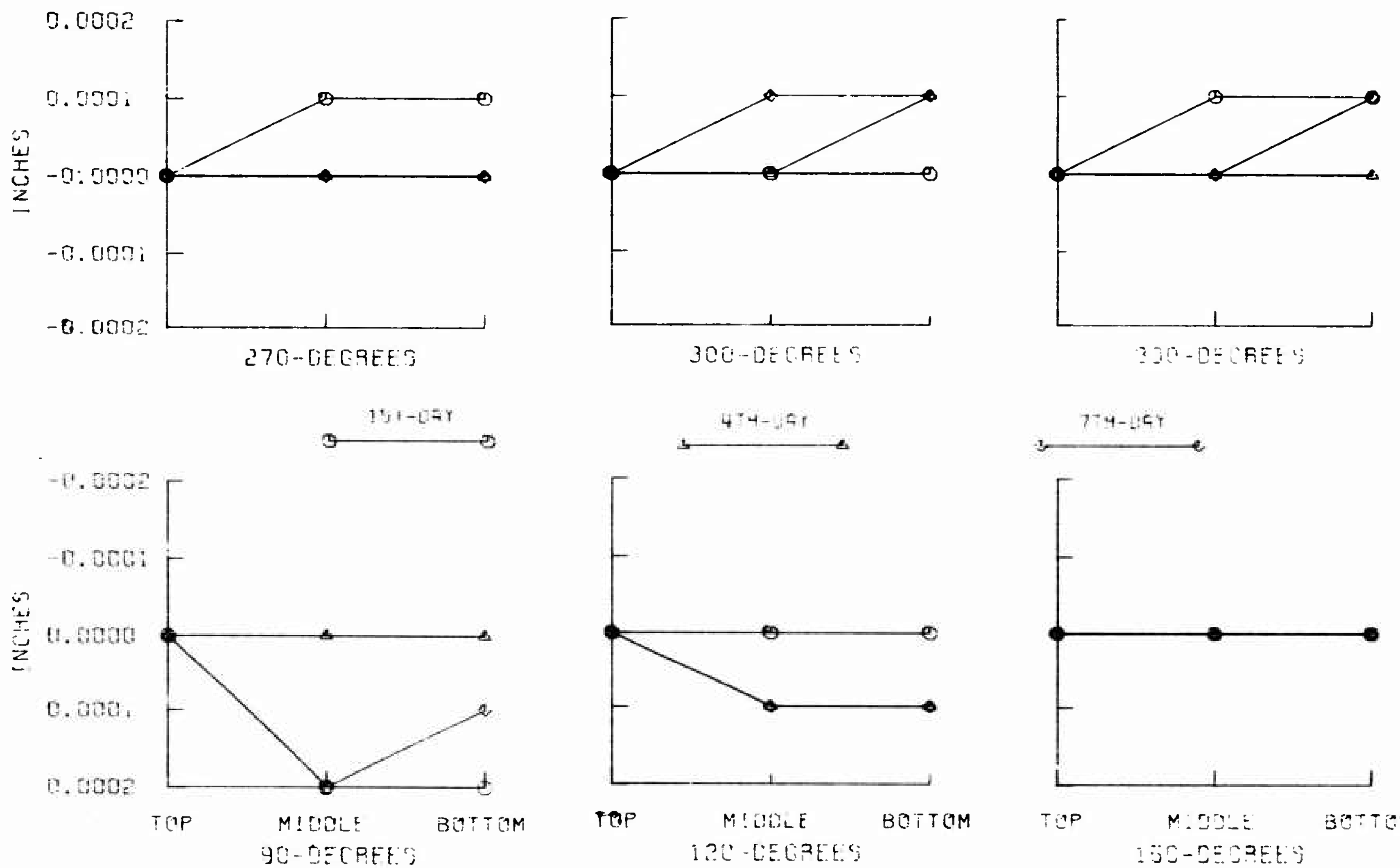


FIG. 13b. BORE TAPER FOR SAMPLE NUMBER 6 WOUND WITH 1 POUND TENSION, 1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

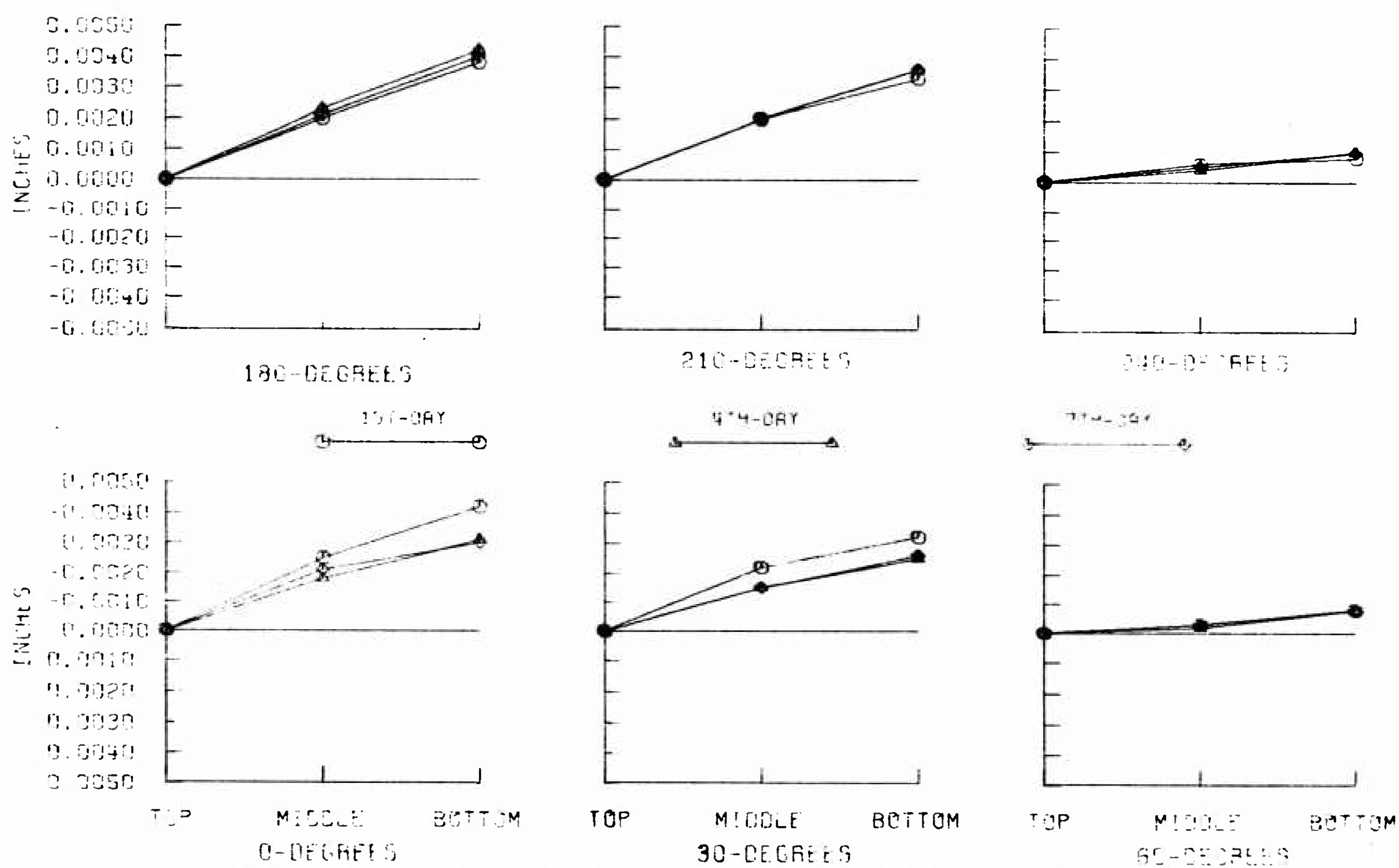


FIG. 14a : BORE TAPER FOR SAMPLE NUMBER 5 WOUND WITH
1 POUND TENSION, 1/2-INCH THICK AND CURED AT 200F
FOR 4 HOURS

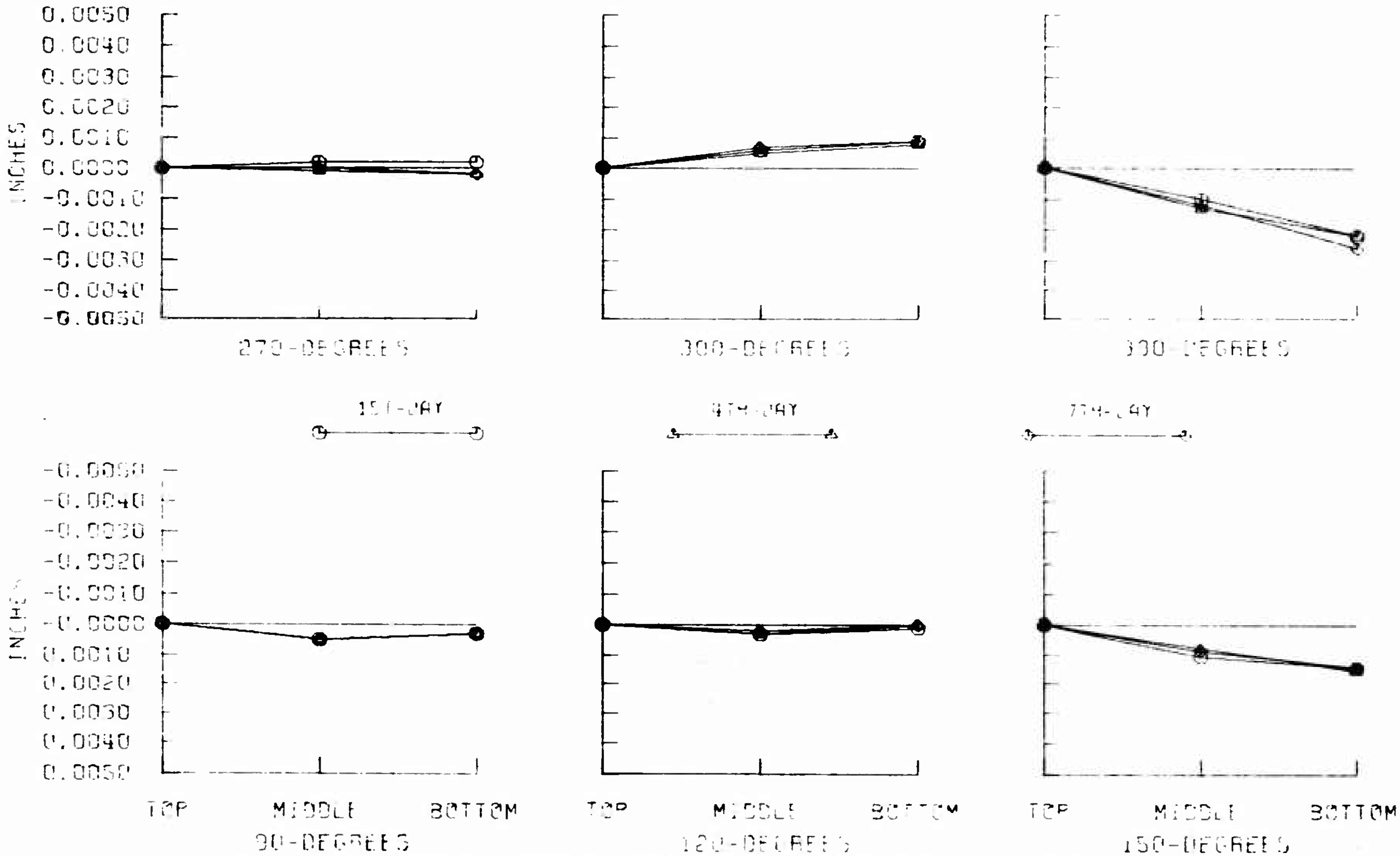


FIG. 14b. BORE TAPER FOR SAMPLE NUMBER 5 WOUND WITH 1 POUND TENSION. 1/2-INCH THICK AND CURED AT 200F FOR 4 HOURS

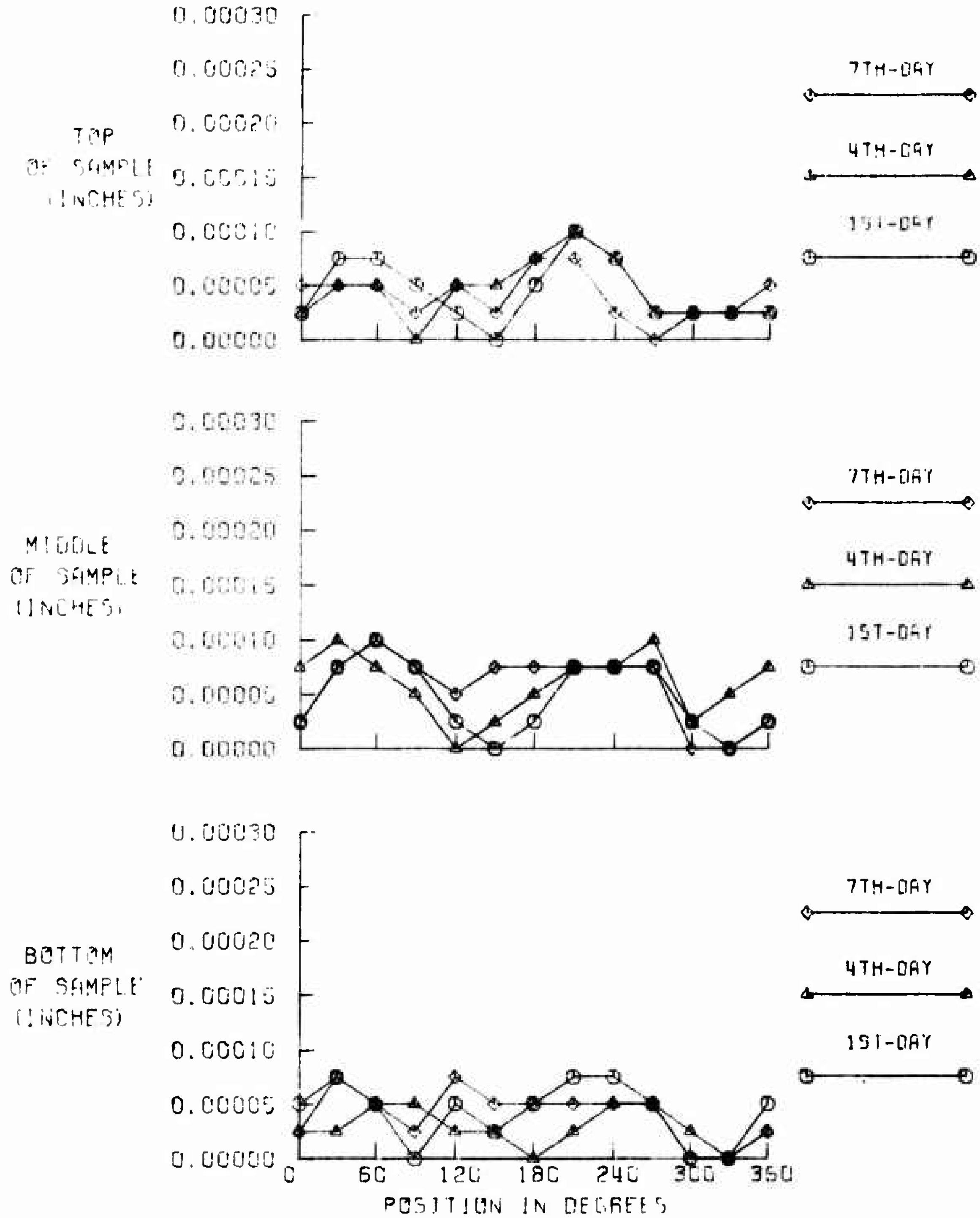


FIG. 15 : VARIATION FROM PERFECT ROUNDNESS FOR SAMPLE NUMBER 4 WOUND WITH 7 POUNDS TENSION, 1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

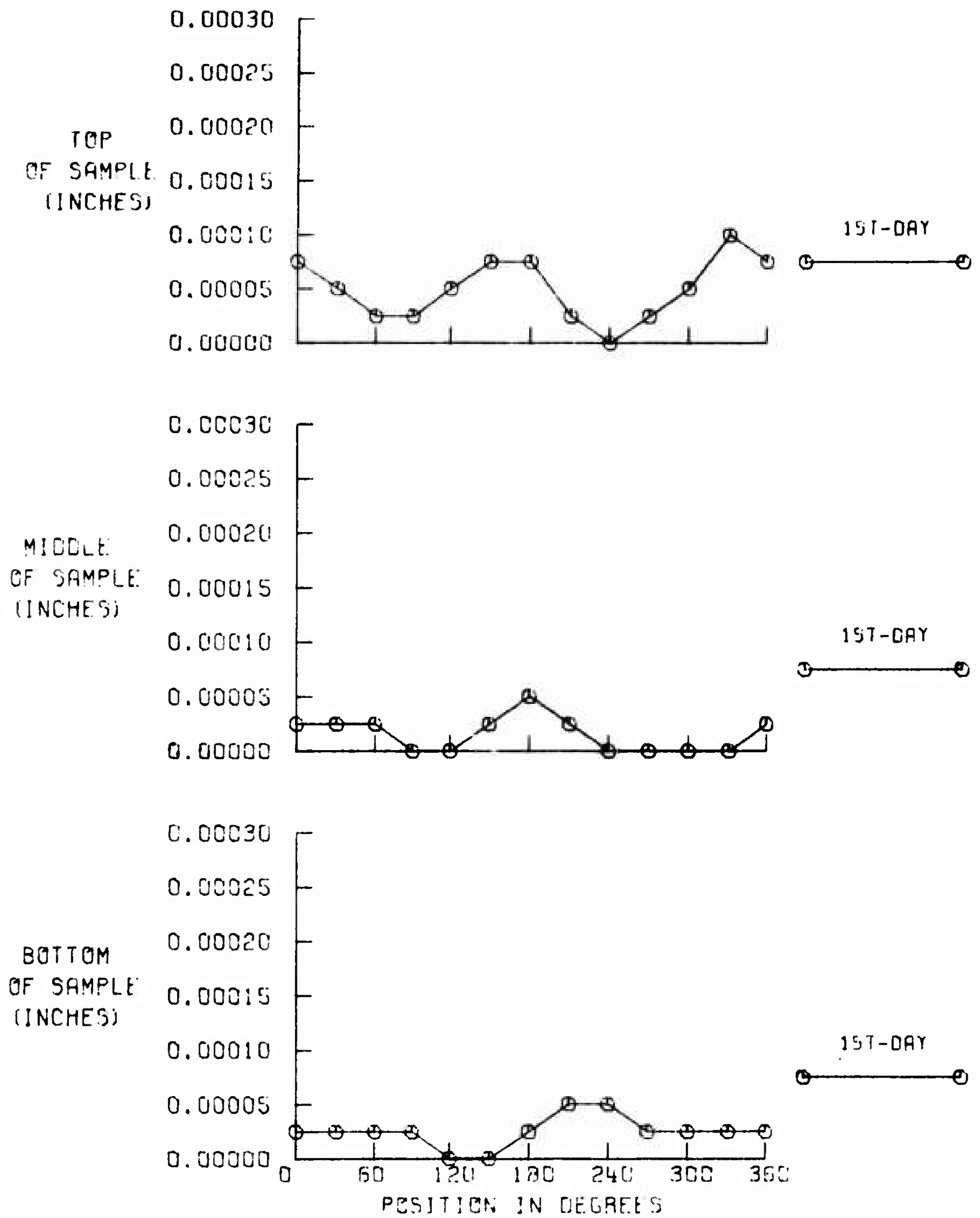


FIG. 16 : VARIATION FROM PERFECT ROUNDNESS FOR SAMPLE NUMBER 6 WOUND WITH 1 POUND TENSION, 1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

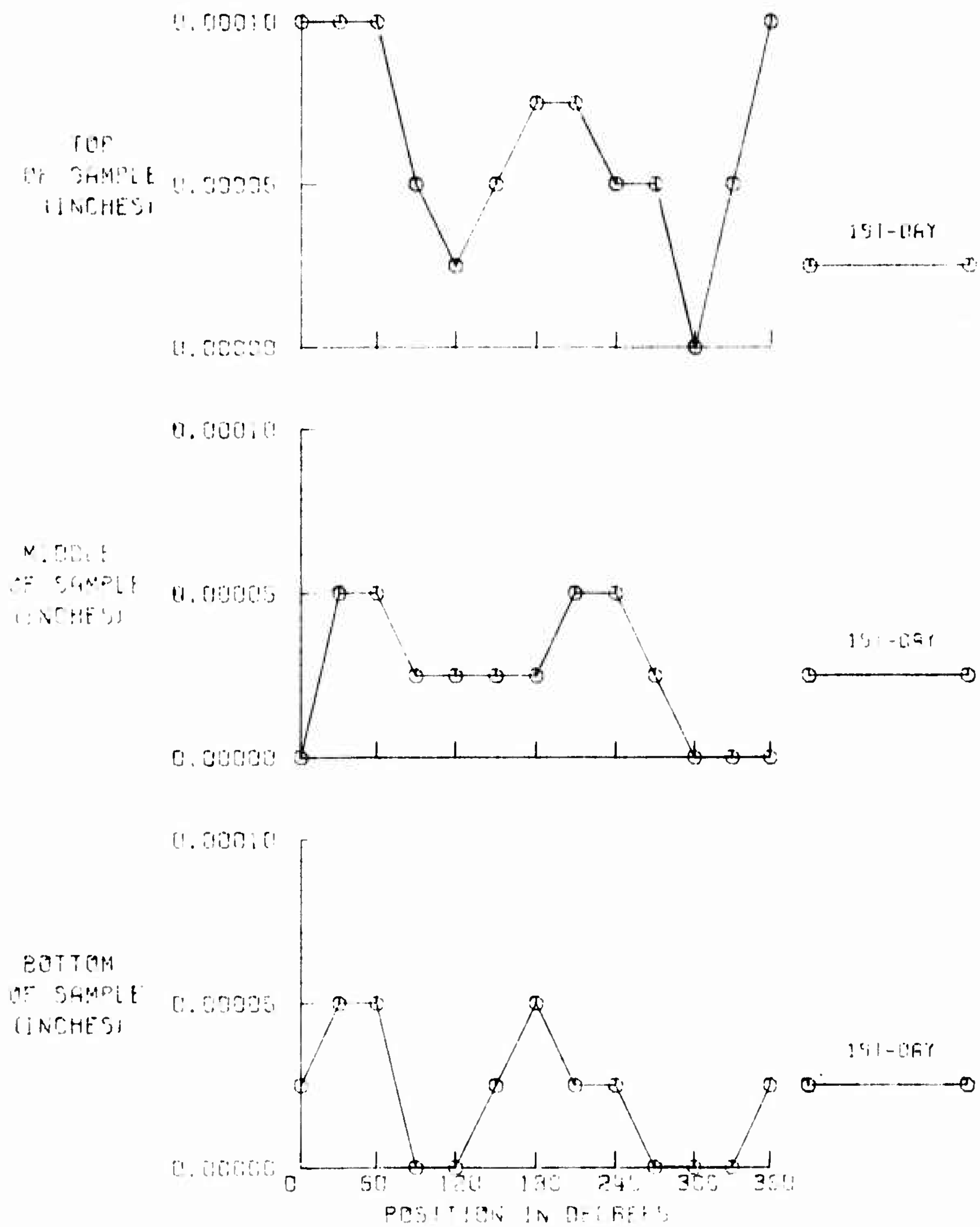


FIG. 17 : VARIATION FROM PERFECT ROUNDNESS FOR SAMPLE NUMBER 8 WOUND WITH 1 POUND TENSION, 1-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

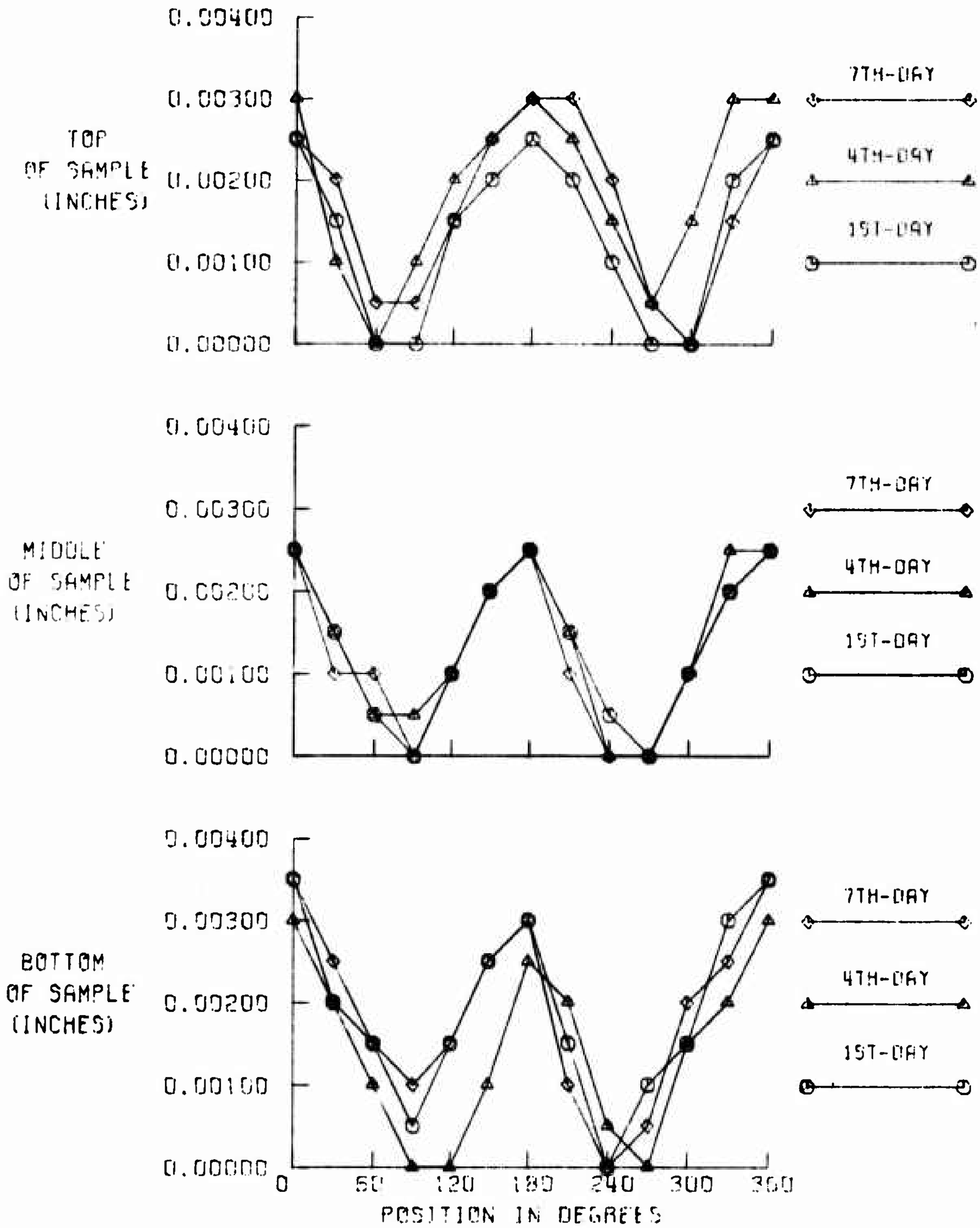


FIG. 18 : VARIATION FROM PERFECT ROUNDNESS FOR SAMPLE NUMBER 5 WOUND WITH 1 POUND TENSION, 1/2 INCH THICK AND CURED AT 200F FOR 4 HOURS

2. Reproducibility test:

Results of the reproducibility test of sample 6, composite samples 9 and 10, is depicted in Figures 19 through 21 and Appendix C. Two sets of measurements were performed, namely the variation in diameter and bore taper. Measurements were taken on the 1st and 7th day after curing. All of the samples, 6, 9 and 10 were fabricated with a filament tension of one pound, one-half inch thick and cured at room temperature, 70°F. Figures 19, 20 and 21 show the variation in diameter for samples 6, 9 and 10 respectively. One will note a variation from .0013 inches to .0014 inches for the 7th Day reading of sample 6, while for sample 9 the 7th Day readings vary from .0013 inches to .0016 inches, a reasonable reproduction of sample 6. On the other hand, sample 10 shows a variation from .0005 inches to .0016 inches which is a poor reproduction of sample 6. The bore taper measurements, Appendix C, does not show an appreciable difference between the three samples.

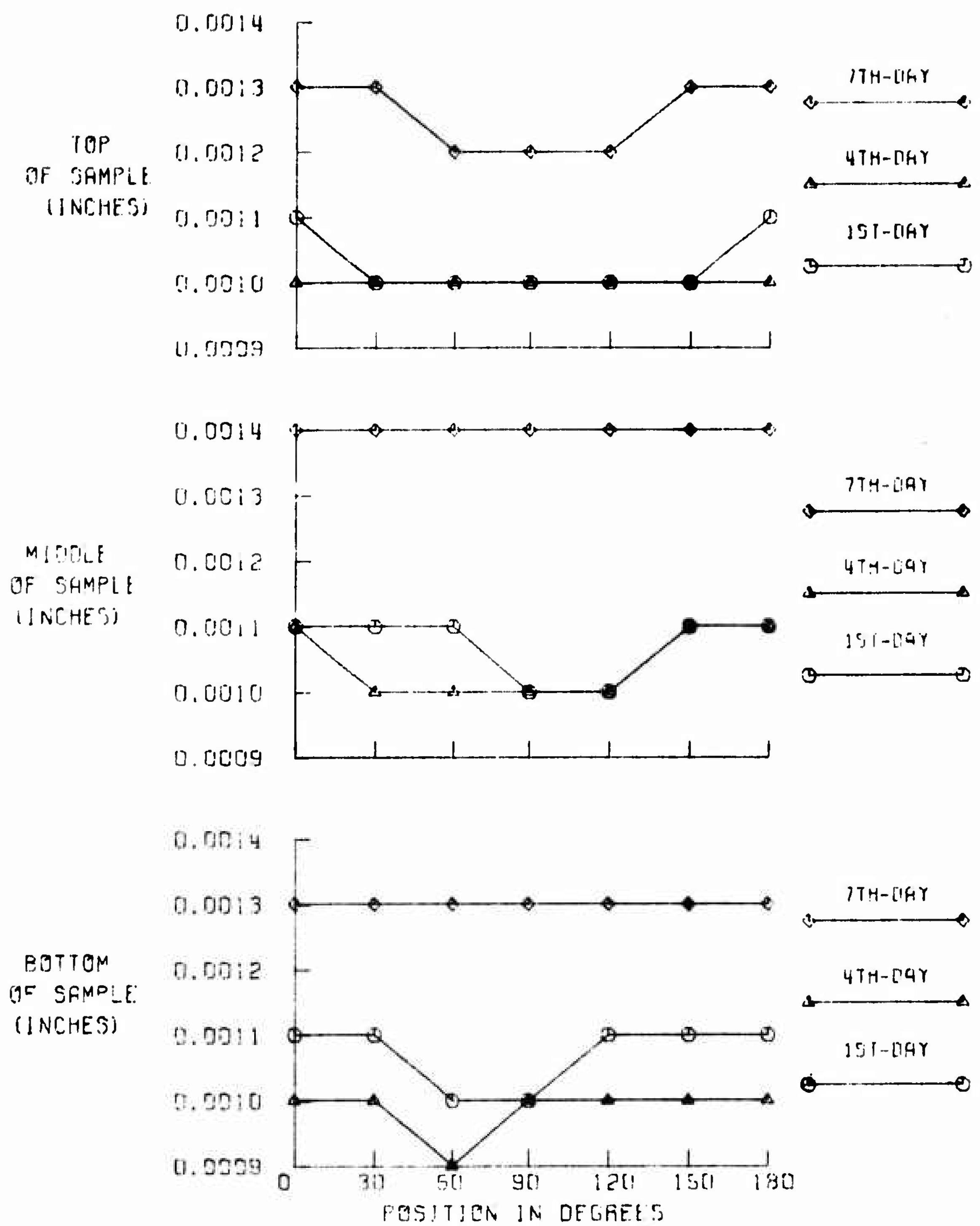


FIG. 19 : DIAMETRICAL VARIATION FROM THE NOMINAL SIZE OF 3.6872 INCHES FOR SAMPLE NUMBER 6 WOUND WITH 1 POUND TENSION, 1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

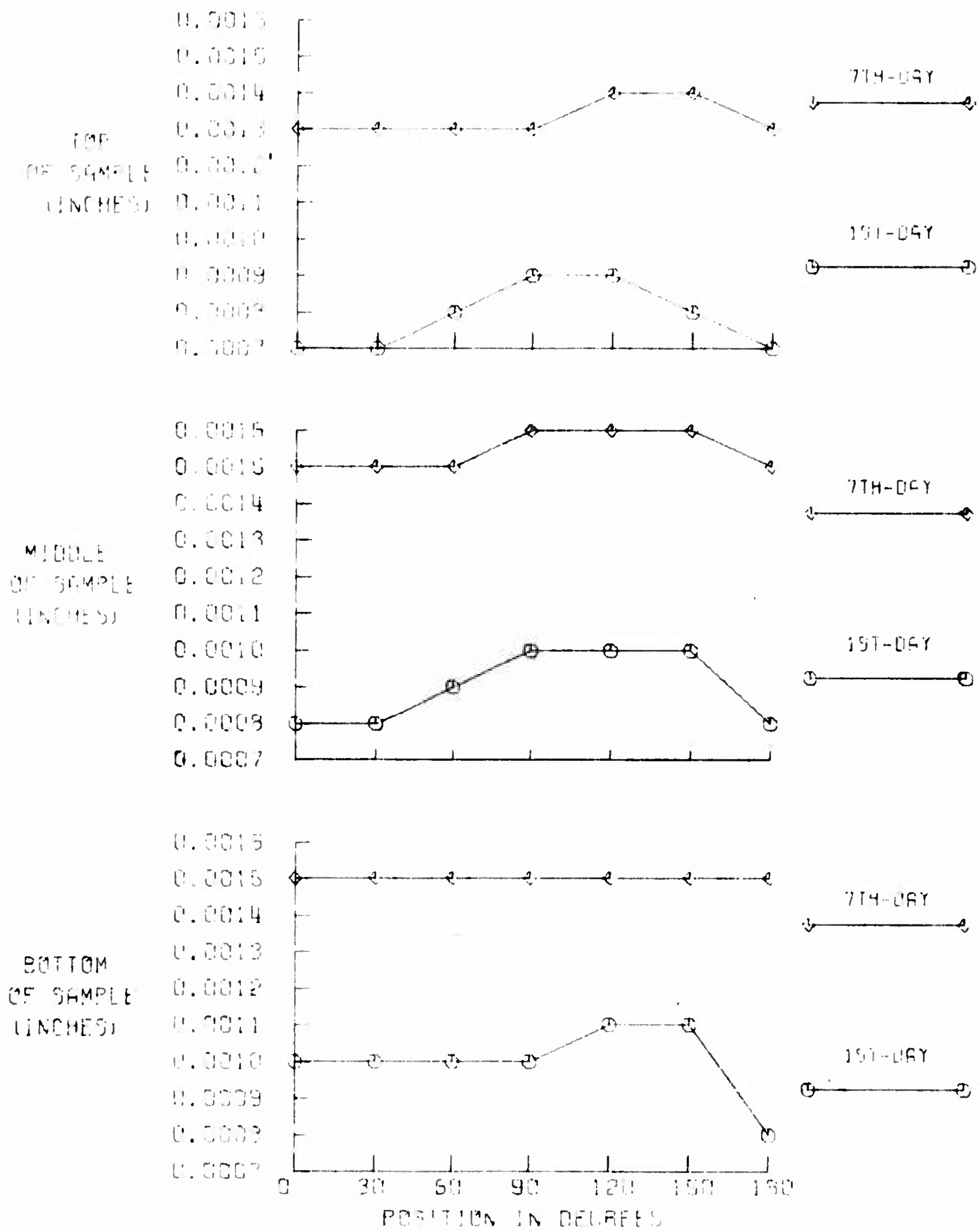


FIG. 20 DIAMETRICAL VARIATION FROM THE NOMINAL SIZE OF 3.0872 INCHES FOR SAMPLE NUMBER 9 WOUND WITH 1 POUND TENSION, 1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

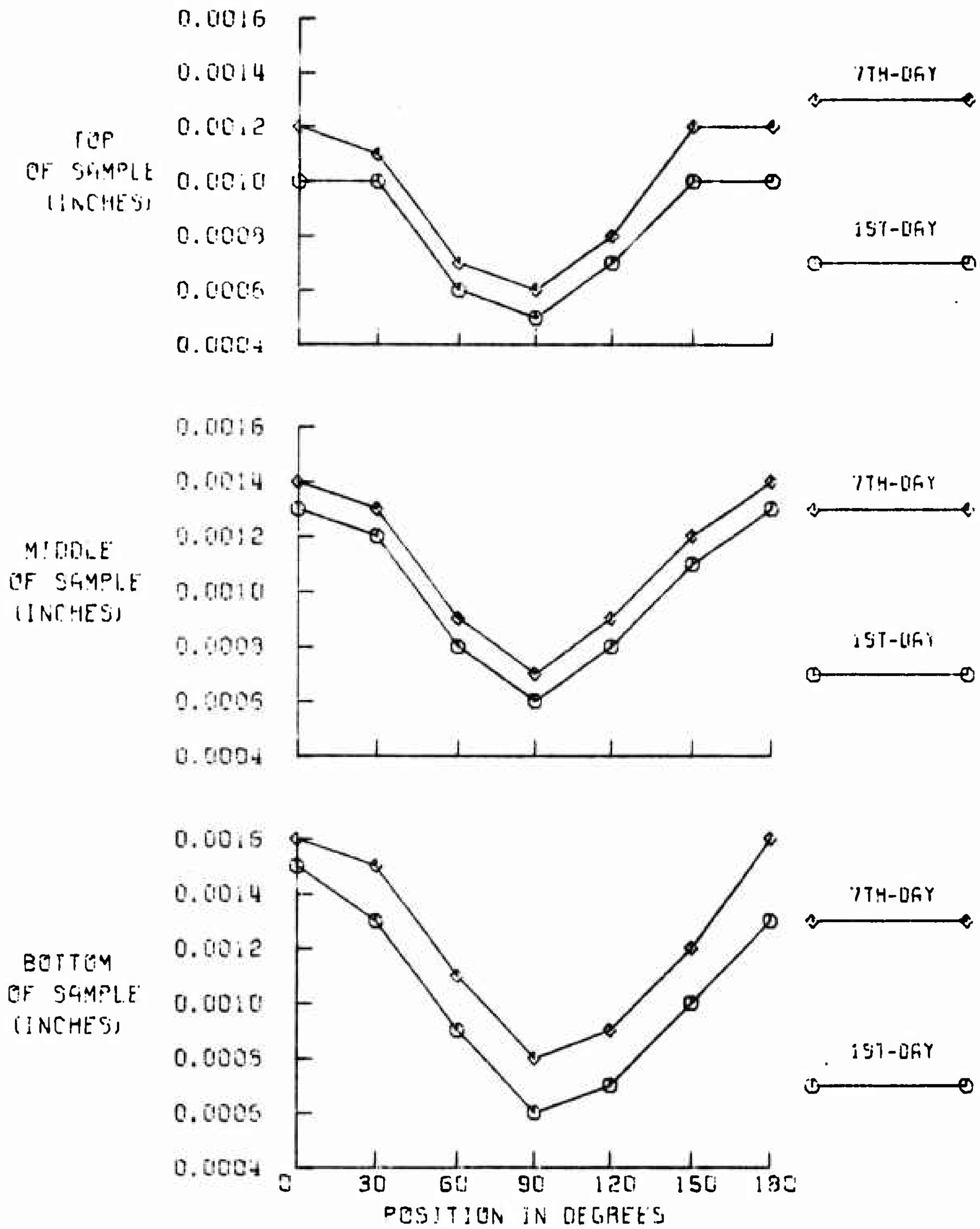


FIG. 21 : DIAMETRICAL VARIATION FROM THE NOMINAL SIZE OF 3.6872 INCHES FOR SAMPLE NUMBER 10 WOUND WITH 1 POUND TENSION, 1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

3. Elevated temperature test:

Results of the elevated temperature test is reported in Tables II through V and in Appendix D. In both samples, 4 and 6, there is a shrinkage in the diameter of about .0002 inches after curing for five and four weeks respectively, Tables II and III. After being heated for the first time for an hour at 110°F and then cooled to ambient temperature for twenty hours sample 6 shrinks approximately .0003 inches while sample 4 only shrinks approximately .0001 inches. The reason for the shrinkage is that upon heating the samples, the compressive stresses are relieved and thus causing the sample to reduce in size. One notices a large shrinkage in sample number 4 because it was wound with a much higher filament tension, seven pounds causing larger compressive stresses. Upon cooling, the inside diameter of both samples expand back to the sizes that they previously were at just before heating. There is a two week curing period between the first heating and the second heating. After being heated a second time the samples are allowed to cool for twenty hours at ambient temperature, 70°F, before a final measurement is taken. These measurements indicate that sample 4 returned to just about the same size as recorded on the 7th Day reading while sample 6 is about .0001 inches smaller than the 7th Day reading. The results of this preliminary test seems to indicate that the samples have stabilized.

It is interesting to note that the readings during the second heating of sample 4 are not affected by the elevated temperature, Table II. In this sample the compressive stresses

were relieved in the first heating and the sample is stable under moderate temperatures.

There was an appreciable uniform change in the width of both samples, 4 and 6 during the heating cycles, see Tables IV and V. One will note however that the samples returned approximately to the same dimensions that were measured before any heating took place.

7 DAYS AFTER BEING WOUND (7TH-DAY READING)

Angular Position	Position Bottom	Middle	Top
0	12*	11	11
30	12	12	11
60	12	12	11
90	12	12	10
120	11	11	10
150	11	11	10

5 WEEKS AFTER BEING WOUND (BEFORE HEATING)

0	10	10	9
30	10	10	10
60	10	10	10
90	10	10	9
120	10	9	9
150	10	9	10

5 WEEKS AFTER BEING WOUND (AFTER HEATING)

0	9	8	8
30	10	9	9
60	10	9	9
90	10	9	8
120	9	8	7
150	9	8	9

7 WEEKS AFTER BEING WOUND (BEFORE HEATING)

0	10	10	9
30	11	10	10
60	11	10	10
90	10	10	9
120	10	10	9
150	10	9	10

7 WEEKS AFTER BEING WOUND (AFTER HEATING)

0	11	11	10
30	12	12	11
60	12	12	11
90	12	11	11
120	11	10	10
150	11	10	11

TABLE II: Diametrical Variation of Sample 4 Before and After Heating

* All readings are in ten thousandths of an inch.

	7 DAYS AFTER BEING WOUND (7TH-DAY READING)		
		Position	
Angular Position	Bottom	Middle	Top
0	13*	14	13
30	13	14	13
60	13	14	12
90	13	14	12
120	13	14	12
150	13	14	13
	4 WEEKS AFTER BEING WOUND (BEFORE HEATING)		
0	11	12	12
30	11	12	11
60	11	11	11
90	11	11	10
120	11	11	11
150	11	11	12
	4 WEEKS AFTER BEING WOUND (AFTER HEATING)		
0	9	9	8
30	8	9	8
60	8	8	8
90	8	8	7
120	8	8	8
150	8	8	9
	6 WEEKS AFTER BEING WOUND (BEFORE HEATING)		
0	11	11	11
30	11	11	11
60	11	11	10
90	11	11	9
120	11	11	10
150	11	11	11
	6 WEEKS AFTER BEING WOUND (20 HOURS AFTER HEATING)		
0	12	13	13
30	12	13	13
60	12	13	12
90	12	12	11
120	12	12	12
150	12	13	14

TABLE III: Diametrical variation of Sample 6 Before and After Heating

* All readings are in ten thousandths

Temp	12	3	6	9
	5 WEEKS AFTER BEING CURED — Position *			
70°F	2.5290"	2.5290"	2.5290"	2.5290"
20 min @ 110°F.	2.5295"	2.5295"	2.5295"	2.5295"
40 min @ 110°F.	2.5300"	2.5300"	2.5300"	2.5300"
60 min @ 110°F.	2.5300"	2.5300"	2.5300"	2.5300"
70°F.	2.5290"	2.5290"	2.5290"	2.5290"
	7 WEEKS AFTER BEING CURED			
70°F.	2.5286"	2.5289"	2.5289"	2.5286"
20 min @ 110°F.	2.5298"	2.5299"	2.5299"	2.5299"
40 min @ 110°F.	2.5299"	2.5300"	2.5300"	2.5300"
60 min @ 110°F.	2.5299"	2.5300"	2.5300"	2.5299"
70°F.	2.5285"	2.5288"	2.5288"	2.5288"

TABLE IV: Variation in width of sample number 4 after being heated to a temperature of 110°F.

Temp	12	3	6	9
	4 WEEKS AFTER BEING CURED — Position			
70°F.	2.5290"	2.5290"	2.5290"	2.5290"
20 min @ 110°F.	2.5310"	2.5305"	2.5307"	2.5308"
40 min @ 110°F.	2.5315"	2.5315"	2.5315"	2.5315"
60 min @ 110°F.	2.5315"	2.5315"	2.5315"	2.5315"
70°F.	2.5290"	2.5290"	2.5293"	2.5292"
	6 WEEKS AFTER BEING CURED			
70°F.	2.5290"	2.5290"	2.5290"	2.5290"
20 min @ 110°F.	2.5308"	2.5308"	2.5308"	2.5308"
40 min @ 110°F.	2.5312"	2.5311"	2.5311"	2.5311"
60 min @ 110°F.	2.5318"	2.5318"	2.5316"	2.5316"
70°F.	2.5289"	2.5289"	2.5289"	2.5289"

TABLE V: Variation in width of sample number 6 after being heated to a temperature of 110°F.

* As corresponds to a clock position

4. Dimensional stability test of acme and "V" thread ring gages:

Four acme thread gages were filament wound on master plug 7244328. Samples 11 and 12 were wound with pre-preg material and oven cured; samples 13 and 14 were wet wound and room temperature cured. Diametral variations of samples are shown in Tables VI, VII and VIII.

Samples 11 and 12 were manufactured to verify results derived from the plain ring samples, that is high temperature curing causes distortions. Results of 11 and 12 indicated this is true in thread gages also.

Since master thread plug gage 7244328 had truncated threads, that is, the feather edge of a thread that remains after grinding at each end of a thread plug is removed back to a point where a complete thread cross-section begins, it was necessary to cut and remove some fibers so that the sample could be screwed off the master after curing. Therefore, there was a possibility that the distortions in samples 11 and 12 may not have been caused entirely by the high temperature curing, but also by the cut fibers as a result of stress relief.

To determine if the distortions were caused by the curing method and/or removed fibers, samples 13 and 14 were wet-wound and room temperature cured on the same master. Results shown in Table VIII indicated distortions similar to samples 11 and 12.

Since the curing method was changed for sample 13 and 14, samples not requiring fibers to be removed were wound and room temperature cured. Samples 15 and 16 were wound on master plug gage 5220-751-5177 (V thread) and sample 17 was wound on master thread plug 7244833 (acme

thread). Both masters had incomplete thread ends, that is, the feather edge was not removed so that samples could be screwed off without cutting and removing fibers. Results shown in Tables IX and X clearly show vast improvements in size, roundness, flank angle and pitch.

Samples 11 through 14 had deviations on diameters from master of .0033 inches to .0126 inches after initial curing, whereas, samples 15 through 17 diameter had deviations of .0002 inches Min to .0022 inches Max after initial curing. Also, samples 15 through showed pitch errors of .0002 inches to .0011 inches and flank angle errors of 0°4' to 0°10', whereas, samples 11 through 14 had pitch errors of .0024 inches to .0037 inches and flank angle errors of - 0°15' to + 0°20'.

Results clearly indicate, filament wound thread ring gages which are wet wound, room temperature cured with uncut fibers possessed the best dimensional stability. It must be noted also that all samples showed excellent profile geometry in radii, chambers, straightness of thread flanks and surface finish.

B. Molding Process:

1. Three samples, 18, 19, 20 were vacuum molded (see figure 7) using a lucite mold and master plug gage 7244238. All three showed voids of various sizes in the thread area. The voids were a result of insufficient material flow and fiber packing.

The use of the molding process with vacuum alone, proved to be inadequate to properly distribute the high fiber concentration (approx 40%) necessary to eliminate the voids.

Small cylindrical specimens molded under pressure showed improvements. As a result of our work and discussions with composite material companies, it is felt that a pressurized molded process assisted by heat and a vacuum could be a solution to the void problem. The remaining project time did not allow investigation of such a molding process.

2. An air-gage head that had been molded of cut aluminum fibers and epoxy was used on a trial basis in the shop area to check bore and rifling diameter on the 175mm cannon tube. This was successfully molded with absence of voids since high fiber concentrations were not required due to the relative unimportance of dimensional stability for this application. The function of the gage head is to carry air or electronic transducers and related elements through the tube to measure bore and rifling diameters and does not affect the measuring accuracy of the system. The present gage heads are made of aluminum. Results were very satisfactory for the following reasons:

a. Weight reduction over aluminum was approximately 50%.

b. Wear in checking 50 tubes (3800 linear feet) was .0004 inches.

c. Inspection personnel were enthusiastic about its use.

d. The material having a low coefficient of friction is very easily pushed along the bore resulting in minimal wear.

Minor Diameter 1st Day

Position	Master	Vertical Center Line Measured	Vertical Center Line Variation	Horizontal Center Line Measured	Horizontal Center Line Variation
Top	3.4651	3.4749	.0098	3.4744	.0093
Middle	3.4651	3.4741	.0090	3.4741	.0090
Bottom	3.4651	3.4672	.0021	3.4688	.0037

Minor Diameter 4th Day

Position	Master	Vertical Center Line Measured	Vertical Center Line Variation	Horizontal Center Line Measured	Horizontal Center Line Variation
Top	3.4651	3.4746	.0095	3.4737	.0086
Middle	3.4651	3.4737	.0086	3.4744	.0093
Bottom	3.4651	3.4676	.0025	3.4719	.0068

Major Diameter 1st Day

Position	Master	Vertical Center Line Measured	Vertical Center Line Variation	Horizontal Center Line Measured	Horizontal Center Line Variation
Top	3.6857	3.6941	.0084	3.6981	.0124
Middle	3.6857	3.6949	.0092	3.6952	.0095
Bottom	3.6857	3.6915	.0058	3.6941	.0084

Major Diameter 4th Day

Position	Master	Vertical Center Line Measured	Vertical Center Line Variation	Horizontal Center Line Measured	Horizontal Center Line Variation
Top	3.6857	3.6969	.0112	3.6967	.0110
Middle	3.6857	3.6959	.0102	3.6953	.0096
Bottom	3.6857	3.6912	.0055	3.6946	.0089

Flank Angle:	Master	14°	27'	to	14°	33'
	Variation	14°	25'	to	15°	0'

Maximum Pitch Error .0037

Table VI: Deviation of Sample 11 From Master Thread Plug Gage (14° 30' Acme With Complete Thread Ends) Wound With 7 Pounds Tension and Gelled at 220°F for 2 Hours, and then Cured at 350°F for 2 Hours and Cooled to Room Temperature.

Minor Diameter 1st Day

Position	Master	Vertical Center Line Measured	Vertical Center Line Variation	Horizontal Center Line Measured	Horizontal Center Line Variation
Top	3.4651	3.4757	.0106	3.4716	.0065
Middle	3.4651	3.4750	.0099	3.4716	.0110
Bottom	3.4651	3.4755	.0104	3.4755	.0104

Minor Diameter 4th Day

Position	Master	Vertical Center Line Measured	Vertical Center Line Variation	Horizontal Center Line Measured	Horizontal Center Line Variation
Top	3.4651	3.4750	.0109	3.4721	.0070
Middle	3.4651	3.4749	.0098	3.4770	.0119
Bottom	3.4651	3.4757	.0106	3.4755	.0104

Major Diameter 1st Day

Position	Master	Vertical Center Line Measured	Vertical Center Line Variation	Horizontal Center Line Measured	Horizontal Center Line Variation
Top	3.6857	3.6964	.0107	3.6943	.0086
Middle	3.6857	3.6983	.0126	3.6950	.0093
Bottom	3.6857	3.6976	.0019		.0120

Major Diameter 4th Day

Position	Master	Vertical Center Line Measured	Vertical Center Line Variation	Horizontal Center Line Measured	Horizontal Center Line Variation
Top	3.6857	3.6965	.0108	3.6941	.0084
Middle	3.6857	3.6971	.0114	3.6947	.0090
Bottom	3.6857	3.6975	.0118	3.6977	.0120

Flank Angle: Master 14° 27' to 14° 33'
Variation 14° 15' to 14° 50'

Maximum Pitch Error .0028

Table VII: Deviation of Sample 12 From Master Thread Plug Gage (14° 30' Acme With Complete Thread Ends) Wound With 7 Pounds Tension and Gelled at 220°F for 2 Hours and then Cured at 350°F for 2 Hours and cooled to Room Temperature.

Minor Diameter

Sample Position		Master	Vertical Center Line Measured	Vertical Center Line Variation	Horizontal Center Line Measured	Horizontal Center Line Variation
16	Top	3.4651	3.4708	.0057	3.4689	.0038
16	Middle	3.4651	3.4756	.0105	3.4700	.0049
16	Bottom	3.4651	3.4725	.0074	3.4696	.0045
17	Top	3.4651	2.4710	.0059	3.4683	.0032
17	Middle	3.4651	3.4735	.0084	3.4702	.0051
17	Bottom	3.4651	3.4705	.0054	2.4702	.0051

Major Diameter

16	Top	3.6857	3.6928	.0071	3.6904	.0047
16	Middle	3.6857	2.6981	.0124	3.6905	.0048
16	Bottom	3.6857	3.6980	.0123	3.6910	.0053
17	Top	3.6857	3.6919	.0062	3.6910	.0053
17	Middle	3.6857	3.6961	.0104	3.6912	.0055
17	Bottom	3.6857	3.6936	.0079	3.6920	.0070

Flank Angle

Sample 16	Master	14° 27'	to 14° 33'
	Variation	14° 15'	to 14° 55'
Sample 17	Master	14° 27'	to 14° 33'
	Variation	14° 25'	to 14° 50'

Maximum Pitch Error

Sample 16	.0028
Sample 17	.0024

Table VIII: Deviations of Samples 13 and 14 From Master Thread Plug Gage (14° 30' Acme With Complete Thread Ends) Wet Wound With 1 Pound Tension and Cured at Room Temperature for 48 Hours.

Pitch Diameter

Sample	Master	1st Day Measured	1st Day Variation	5th Day Measured	5th Day Variation	60th Day Measured	60th Day Variation
15	3.0843	3.0863	.0020	3.0852	.0009	3.0843	.0000
16	3.0843	3.0846	.0003	3.0833	-.001	3.0828	-.0015

	Flank Angle Actual	Flank Angle Measured	Maximum Pitch Error Measured
15	30° 0'	30° 0' to 30° 4'	.0002
16	30° 0'	30° 0' to 30° 4'	.0004

Table IX: Deviations of Pitch Diameter, Thread Pitch and Flank Angle From Master Thread Plug of Samples 15 and 16, Wet-Wound With Incomplete Thread Ends, 1 Pound Tension and Cured at 70°F for 48 Hours

Minor Diameter 1st Day

Position	Master	Vertical Center Line Measured	Vertical Center Line Variation	Horizontal Center Line Measured	Horizontal Center Line Variation
Top	4.4319	4.4328	.0009	4.4317	-.0002
Middle	4.4319	4.4336	.0017	4.4336	.0017
Bottom	4.4319	4.4341	.0022	4.4326	.0007

Minor Diameter 60th Day

Top	4.4319	4.4324	.0005	4.4318	-.0001
Middle	4.4319	4.4330	.0011	4.4329	.0010
Bottom	4.4319	4.4335	.0016	4.4331	.0012

Major Diameter 1st Day

Top	4.7323	4.7335	.0012	4.7333	.0010
Middle	4.7323	4.7339	.0016	4.7342	.0019
Bottom	4.7323	4.7340	.0017	4.7334	.0011

Major Diameter 60th Day

Top	4.7323	4.7332	.0009	4.7334	.0011
Middle	4.7323	4.7335	.0012	4.7331	.0008
Bottom	4.7323	4.7335	.0012	4.7328	.0005

Flank Angle: Master 14° 30'
Variation 14° 20' to 14° 35'

Maximum Pitch Error .0013

Table X: Deviation of Sample 17 From Master Thread Plug Gage (14° 30' Acme With Incomplete Thread Ends) Wet Wound With 1 Pound Tension and Cured at Room Temperature for 48 Hours.

V. CONCLUSION

Results of testing indicated the filament wound thread ring gages which were wet-wound, room-temperature cured with uncut fibers (samples 15 thru 17) possessed the best dimensional stability, However, the required dimensional stability was not obtainable within the fabrication parameters used in this project as shown below:

Deviation from Master on:	Test Results (Range)	Required
Diameter	.0003 to .0022	.001
Flank Angle	$-0°10'$ to $+ 0°5'$	$\pm 0°3'$
Pitch	.0002 to .001	.0003

Additional experimental studies in fabrication techniques, resin systems and materials are required to determine if desired results are obtainable.

The following summarizes Watervliet Arsenal's findings:

A. Filament Winding Process:

1. The temperature at which the sample is cured plays an important part in the dimensional stability of the sample. The tests indicated the higher the curing temperature the greater the distortion.

2. Thickness of the samples did not affect the stability significantly. It should be pointed out that much greater thicknesses may be a problem on larger gages.

3. Tension of winding was not critical until the samples were exposed to an elevated temperature. The high tension sample was not affected by the elevated temperature the second time it was heated.

4. With the fabrication parameters considered it was possible to reproduce a sample reasonably well.

5. Heating the samples relieved the compressive stress within the composites.

B. Molding Process:

It has been determined, in order to mold a precision thread ring with possible acceptable stability, it will be necessary to use a molding process consisting of pressure and heat assisted by a vacuum. Pressure and heat are required to achieve proper fiber distribution of the high fiber population necessary to provide stability.

However, it has been proven that vacuum molding can be used to manufacture various portions of inspection gages other than threads as well as other items where weight or friction is a problem. Vacuum molding is done with relatively simple equipment and in a very short time. Also any parts requiring holes or other configurations are easily molded by making provisions for them in the mold thereby eliminating many machining operations normally required in metal.

VI RECOMMENDATIONS

A. Extend the present study to consider various fabrication techniques in winding complete thread end and acme-thread gages.

B. Consider materials other than "S-Glass" and "E-Glass" for the composite gages.

C. Consider other resin systems besides "EPON 828" and "VERSAMID 140" for the composite gages.

D. Consider vacuum molding composite gages under pressure and heat.

APPENDIX A

Dimensional Data and Pictorial of Master Plug Gage

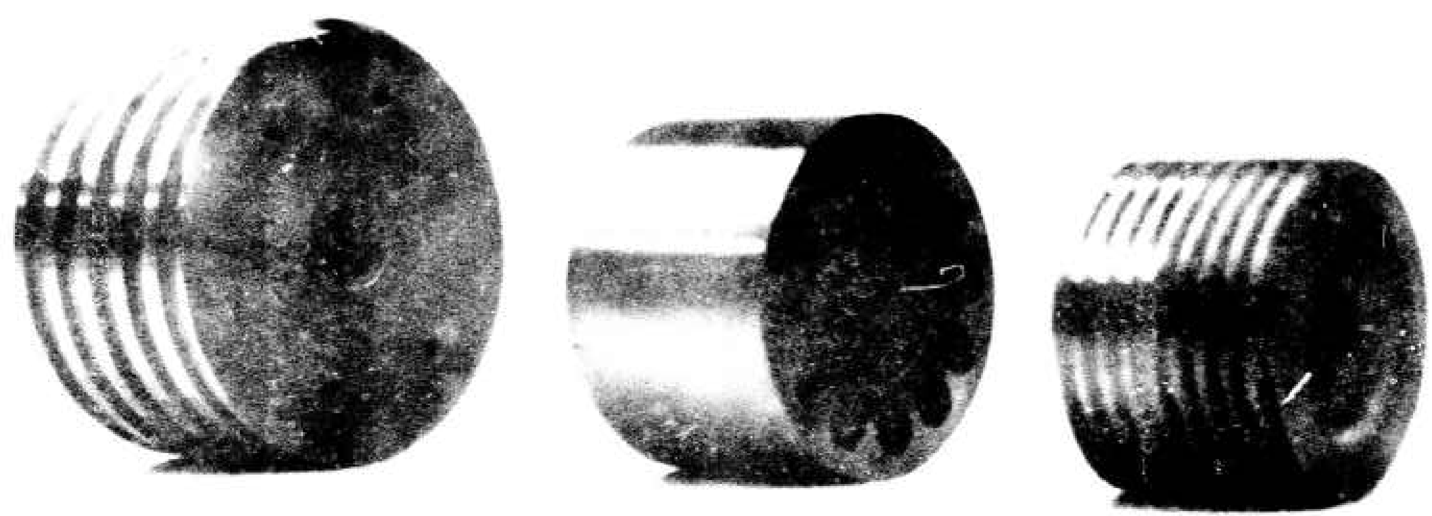


Figure 22 Picture of Master Plug Gages

	Acme Thread Plug 7244328 (Complete Thread Ends)	Acme Thread Plug 7244833 (Incomplete Thread Ends)	"V" Thread Plug 3.250 -4UNC-1A
Major Diameter	3.6857	4.7323	N/A
Minor Diameter	3.4651	4.4319	N/A
Thread Pitch	.333	.500	.250
Flank Angle	14° 30'	14° 30'	30° 0'
Pitch Diameter	N/A	N/A	3.0843

Table XI: Master Thread Plug Gage Data Used as Mandrels to Wind Sample 11 through 17.

APPENDIX B

Test Data of Samples 1 thru 8 not included in the Main Text.

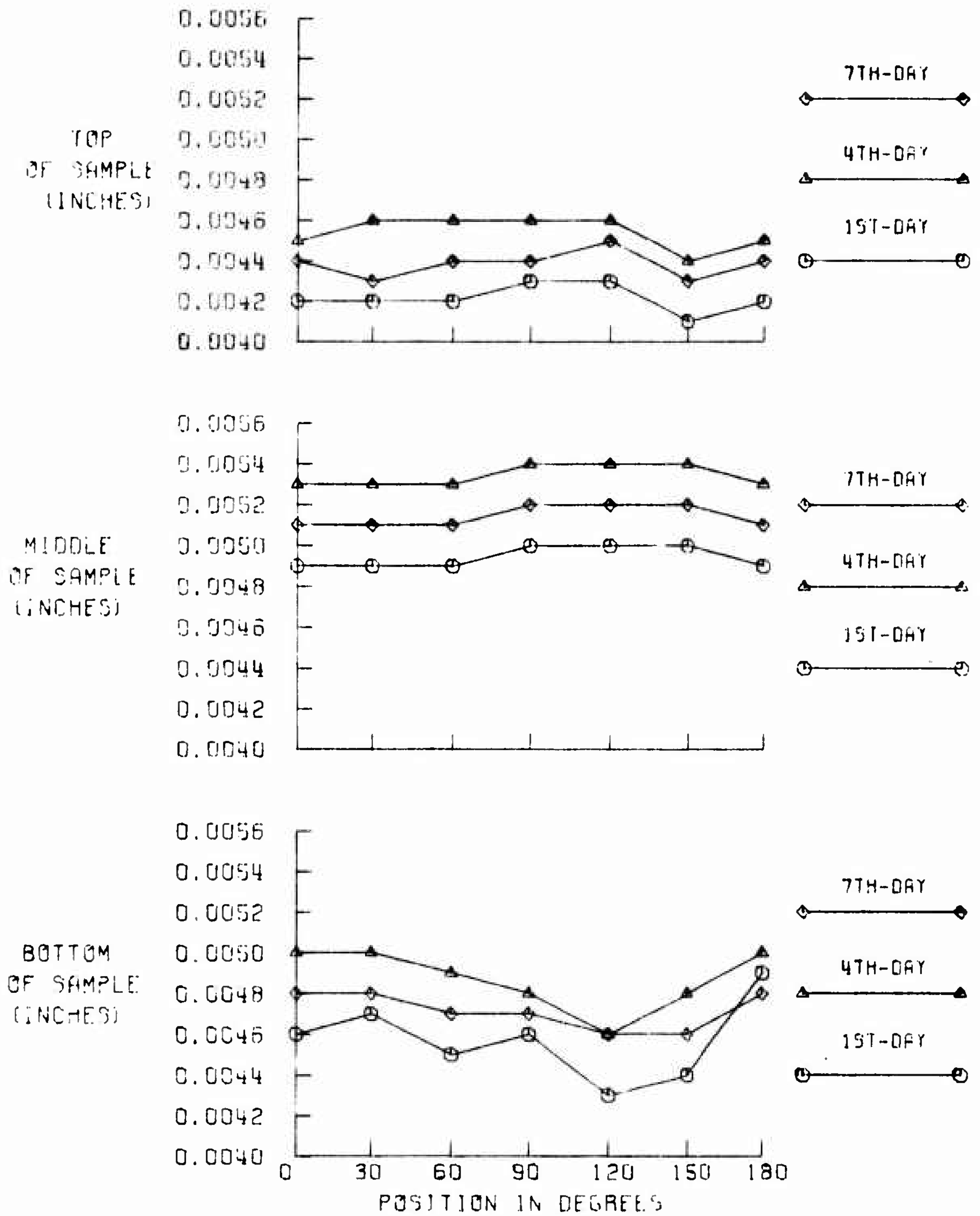


FIG. 23 : DIAMETRICAL VARIATION FROM THE NOMINAL SIZE OF 3.6872 INCHES FOR SAMPLE NUMBER 1 WOUND WITH 7 POUNDS TENSION, 1-INCH THICK AND CURED AT 200 F FOR 4 HOURS

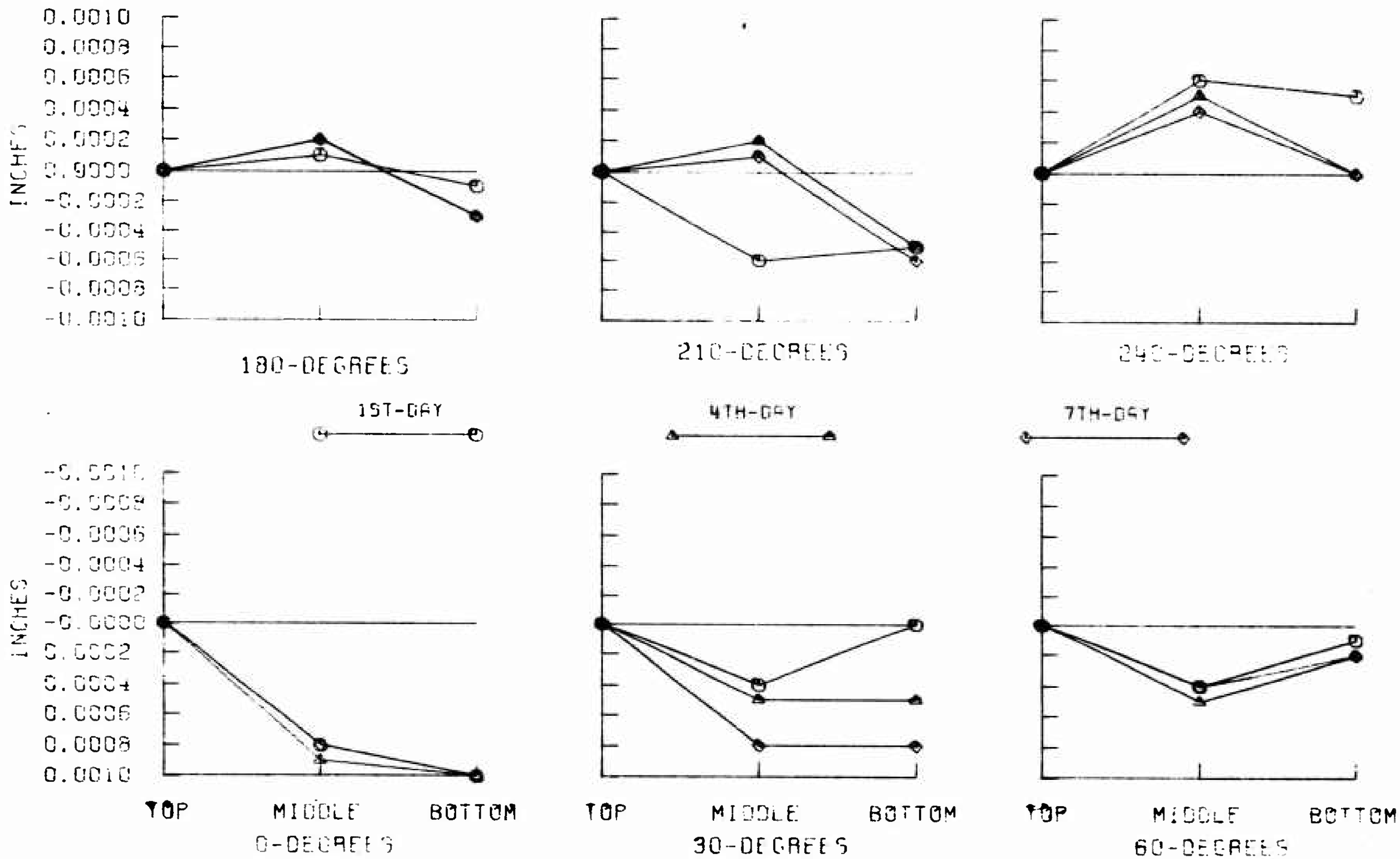


FIG. 24a : BORE TAPER FOR SAMPLE NUMBER 1 WOUND WITH 7 POUNDS TENSION, 1-INCH THICK AND CURED AT 200F FOR 4 HOURS

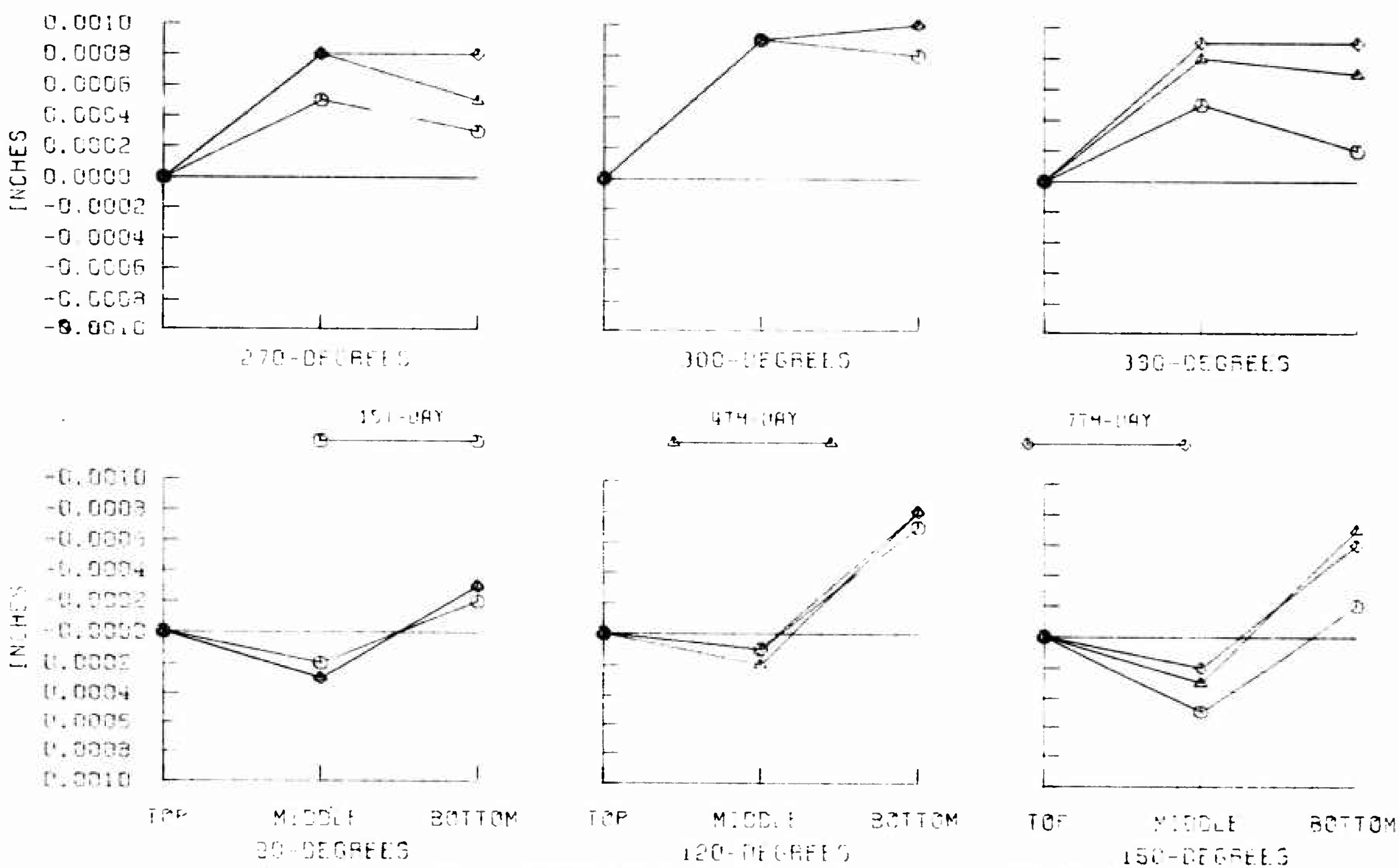


FIG. 24b - BORE TAPER FOR SAMPLE NUMBER 1 WOUND WITH 7 POUNDS TENSION, 1-INCH THICK AND CURED AT 200F FOR 4 HOURS

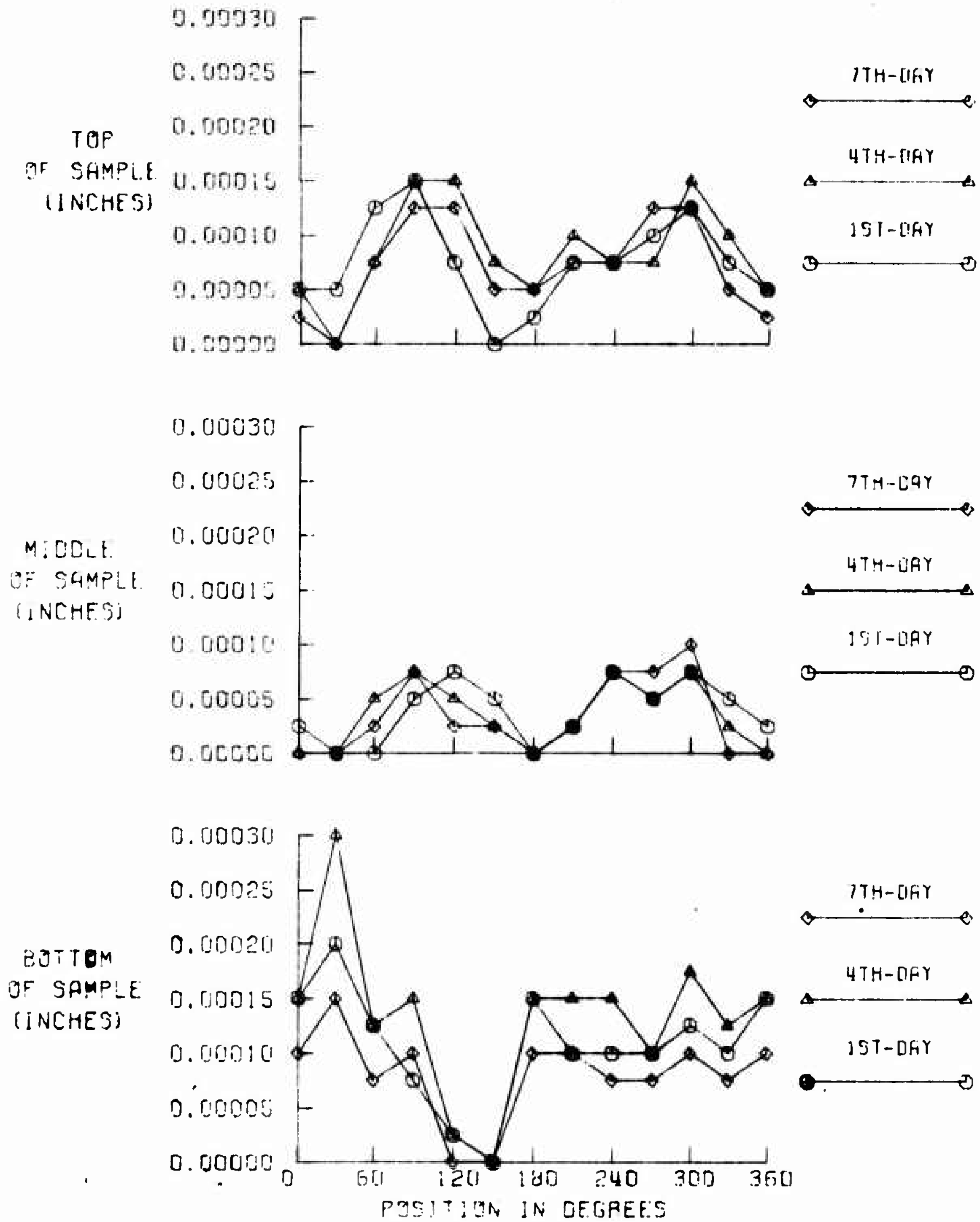


FIG. 25 : VARIATION FROM PERFECT ROUNDNESS FOR SAMPLE NUMBER 1 WOUND WITH 7 POUNDS TENSION, 1-INCH THICK AND CURED AT 200F FOR 4 HOURS

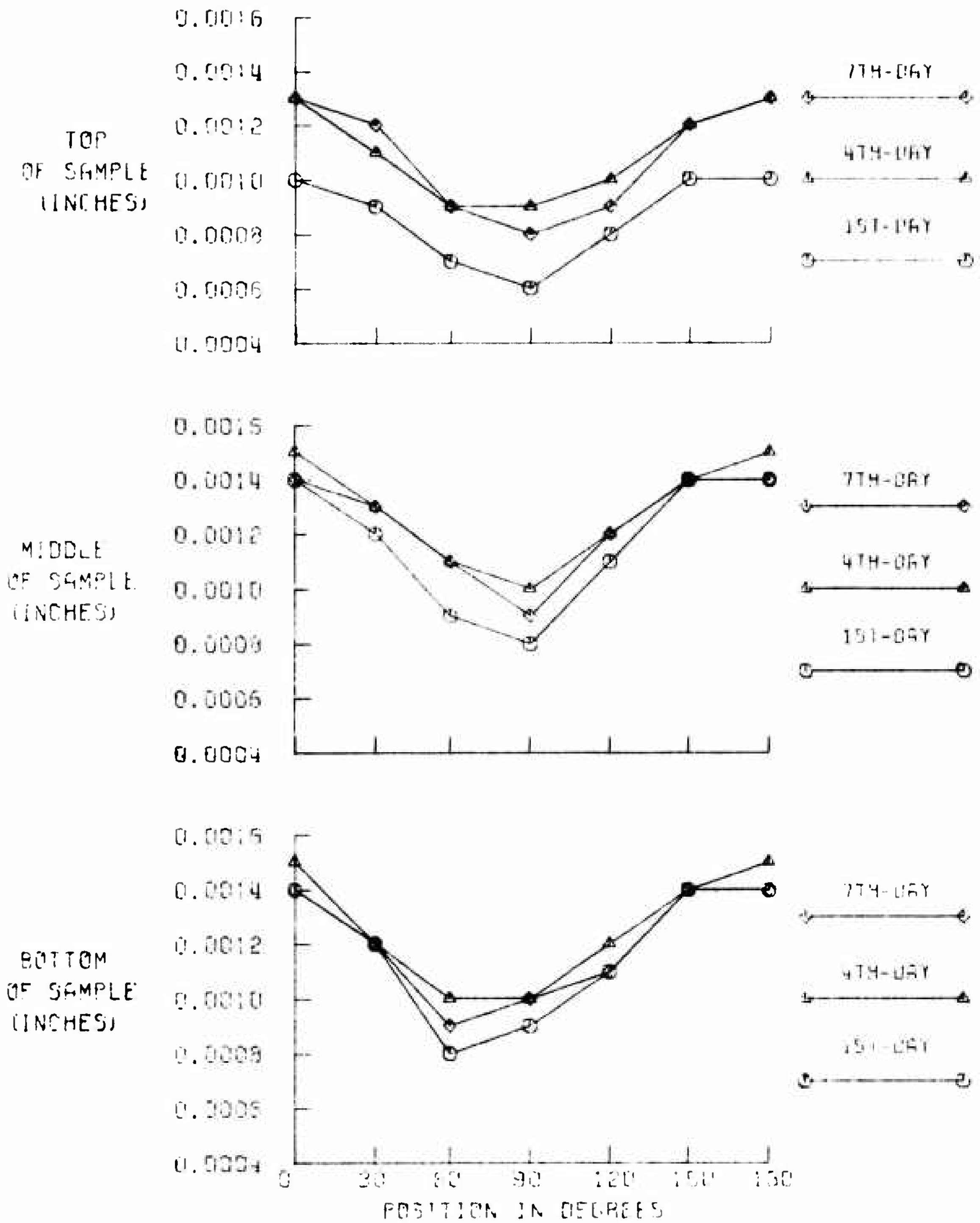


FIG. 26 : DIAMETRICAL VARIATION FROM THE NOMINAL SIZE OF 3.6872 INCHES FOR SAMPLE NUMBER 2 WOUND WITH 7 POUNDS TENSION, 1-INCH THICK ANDCURED AT ROOM TEMPERATURE FOR 48 HOURS

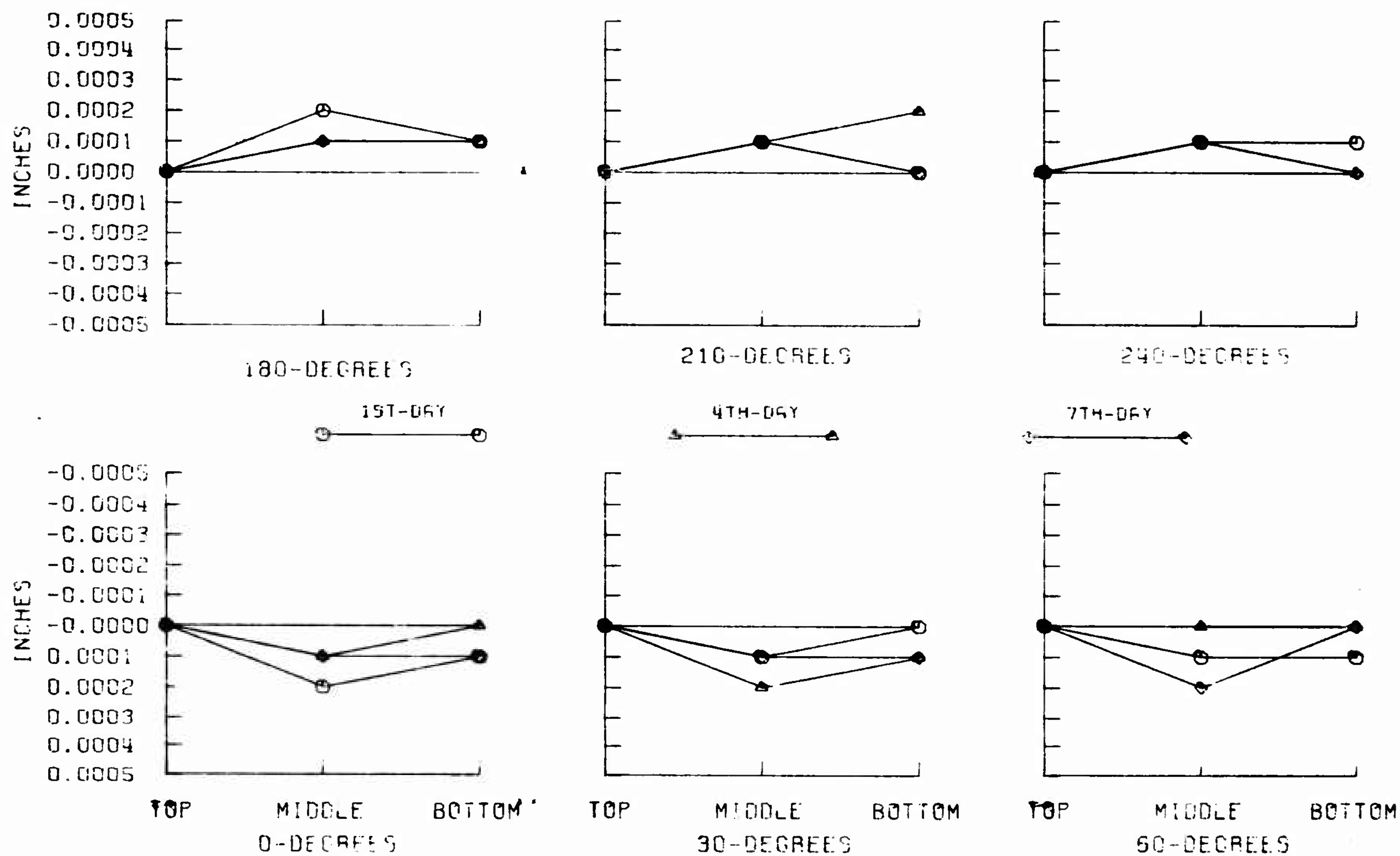


FIG. 27a : BORE TAPER FOR SAMPLE NUMBER 2 WOUND WITH 7 POUNDS TENSION, 1-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

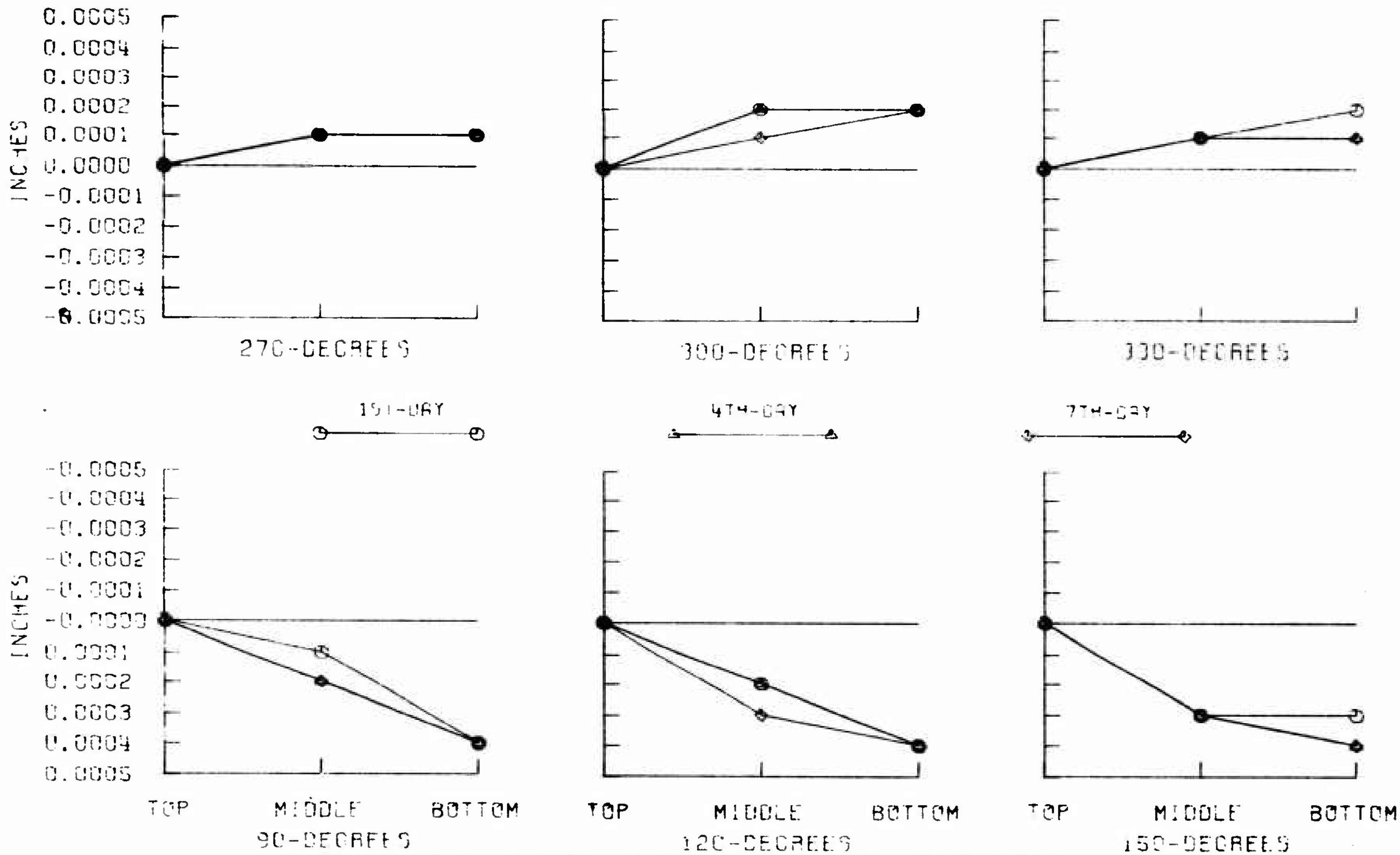


FIG. 27b ; BORE TAPER FOR SAMPLE NUMBER 2 WOUND WITH 7 POUNDS TENSION, 1-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

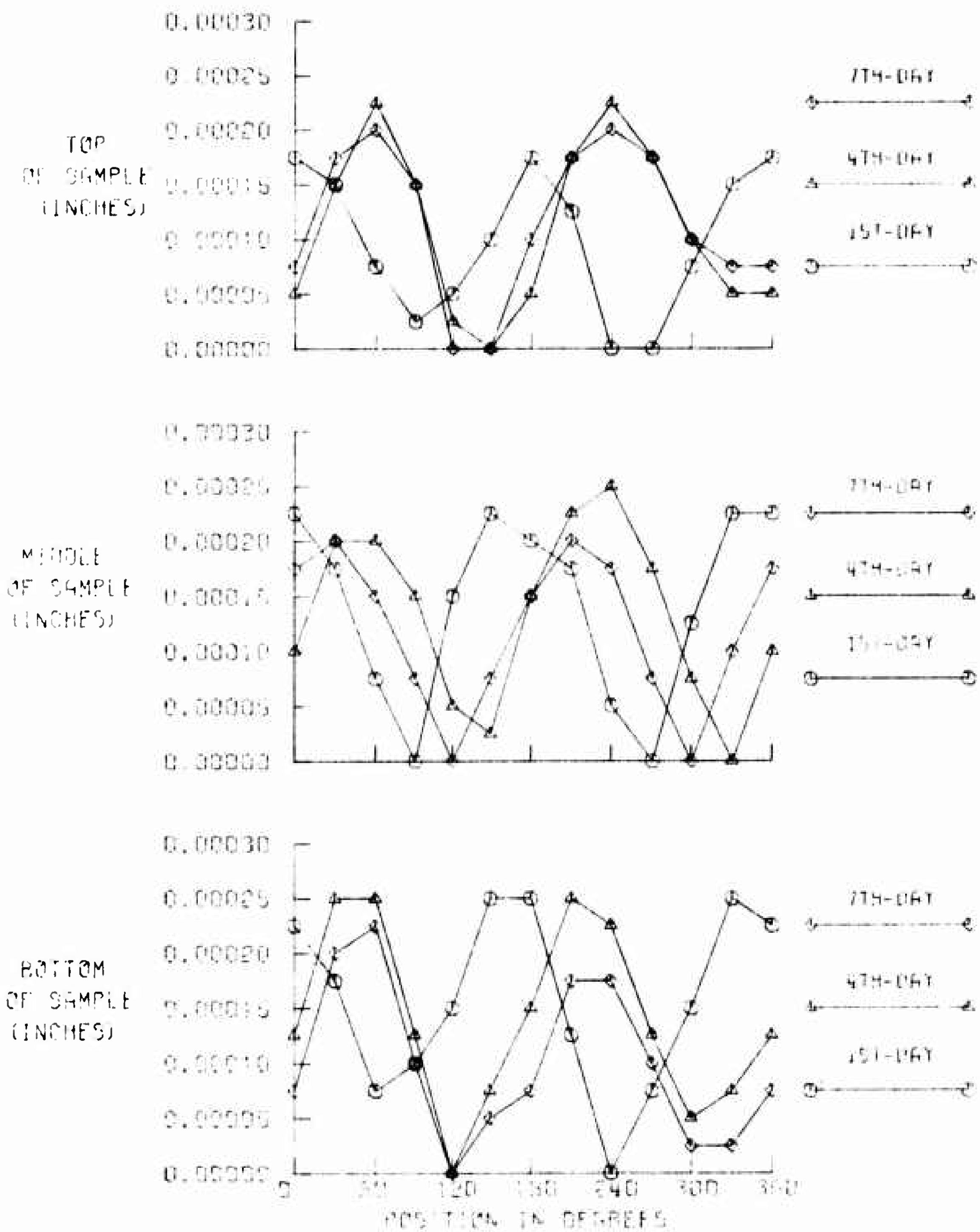


FIG. 28 - VARIATION FROM PERFECT ROUNDNESS FOR SAMPLE NUMBER 2 WOUND WITH 7 POUNDS TENSION, 1-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

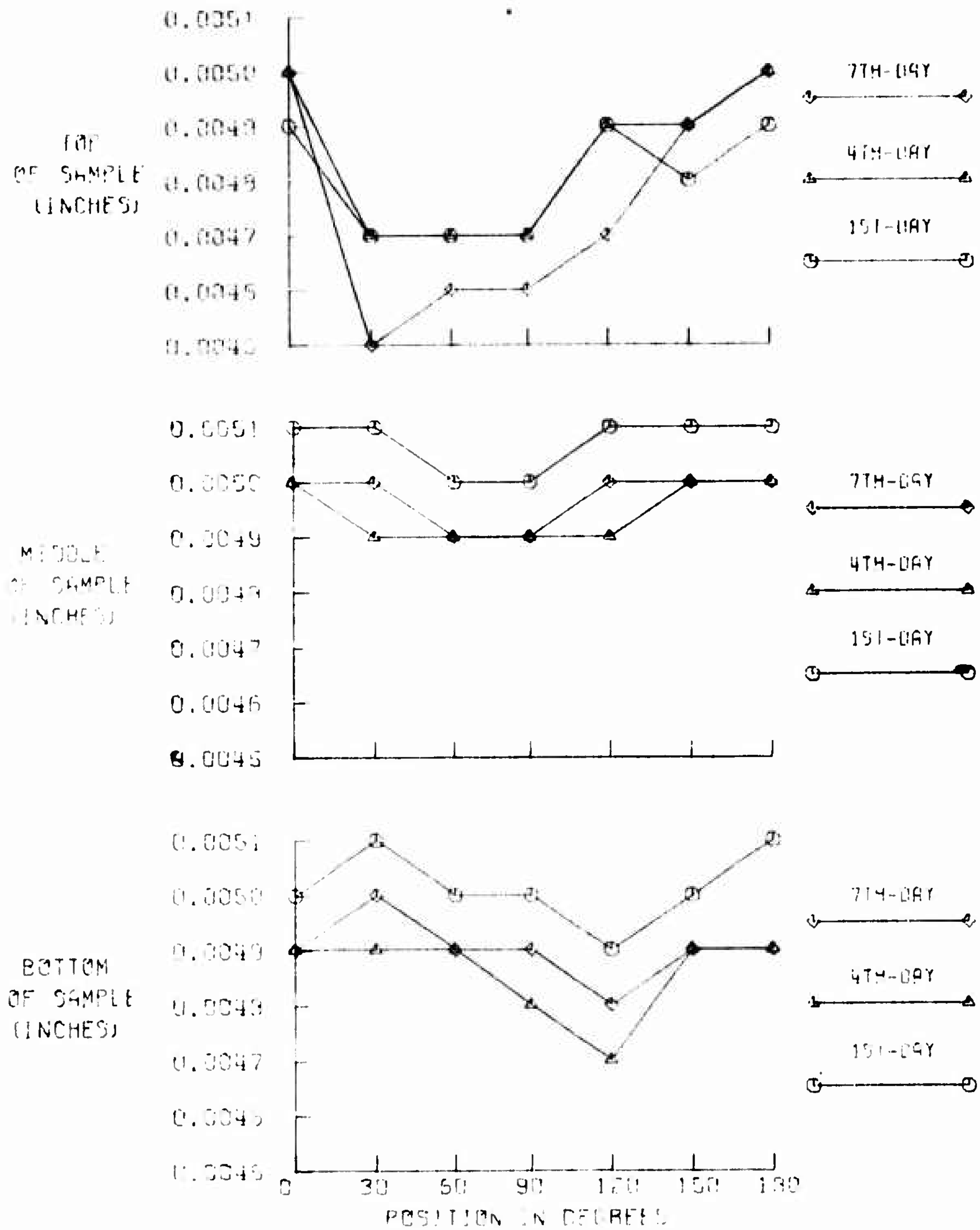


FIG. 29 DIAMETRICAL VARIATION FROM THE NOMINAL SIZE OF 3.6372 INCHES FOR SAMPLE NUMBER 3 WOUND WITH 7 POUNDS TENSION, 1/2-INCH THICK AND CURED AT 200F FOR 4 HOURS

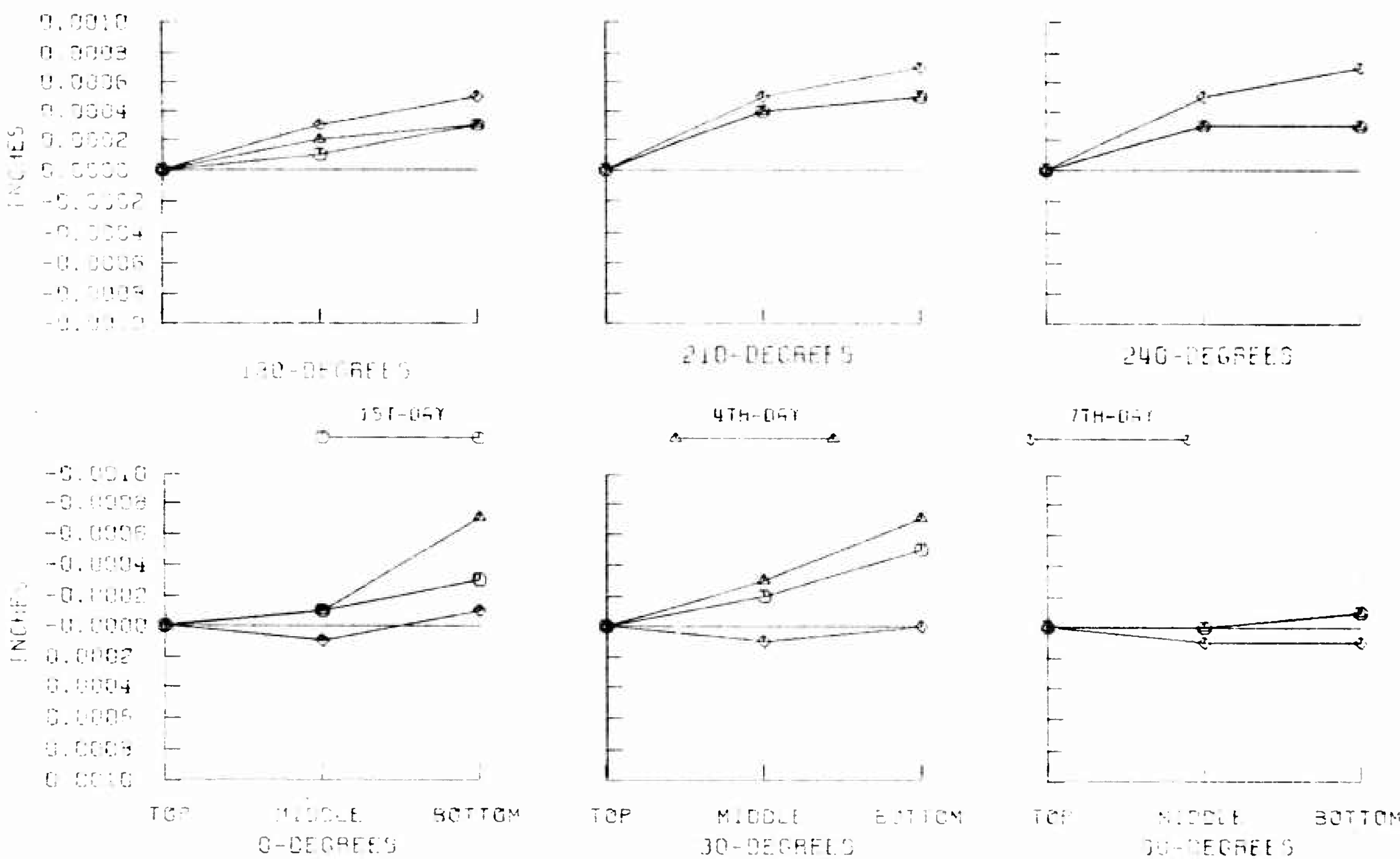


FIG. 30a BORE TAPER FOR SAMPLE NUMBER 3 WOUND WITH
7 POUNDS TENSION, 1/2-INCH THICK AND CURED AT 200F
FOR 4 HOURS

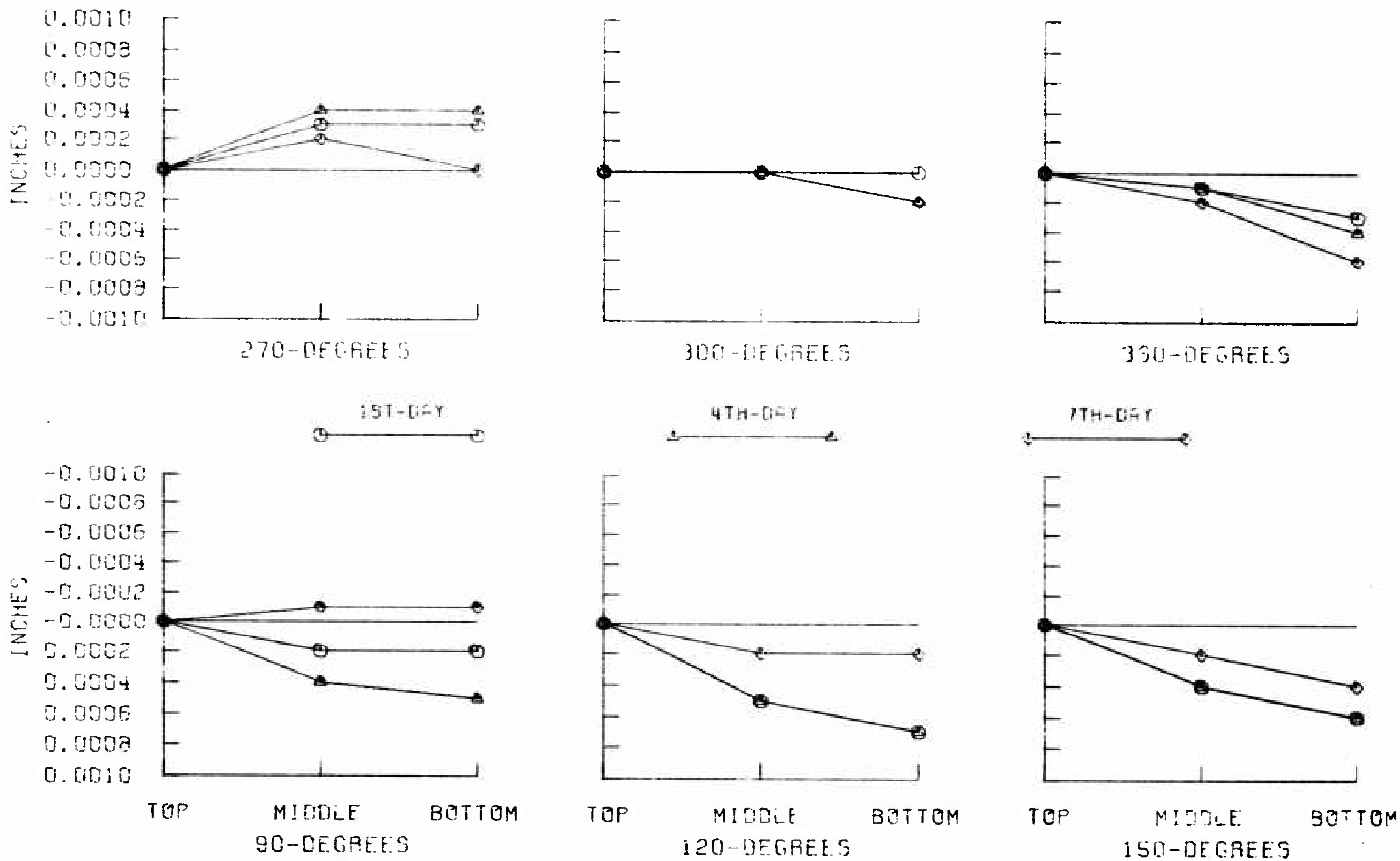


FIG. 30b: BORE TAPER FOR SAMPLE NUMBER 3 WOUND WITH 7 POUNDS TENSION, 1/2-INCH THICK AND CURED AT 200F FOR 4 HOURS

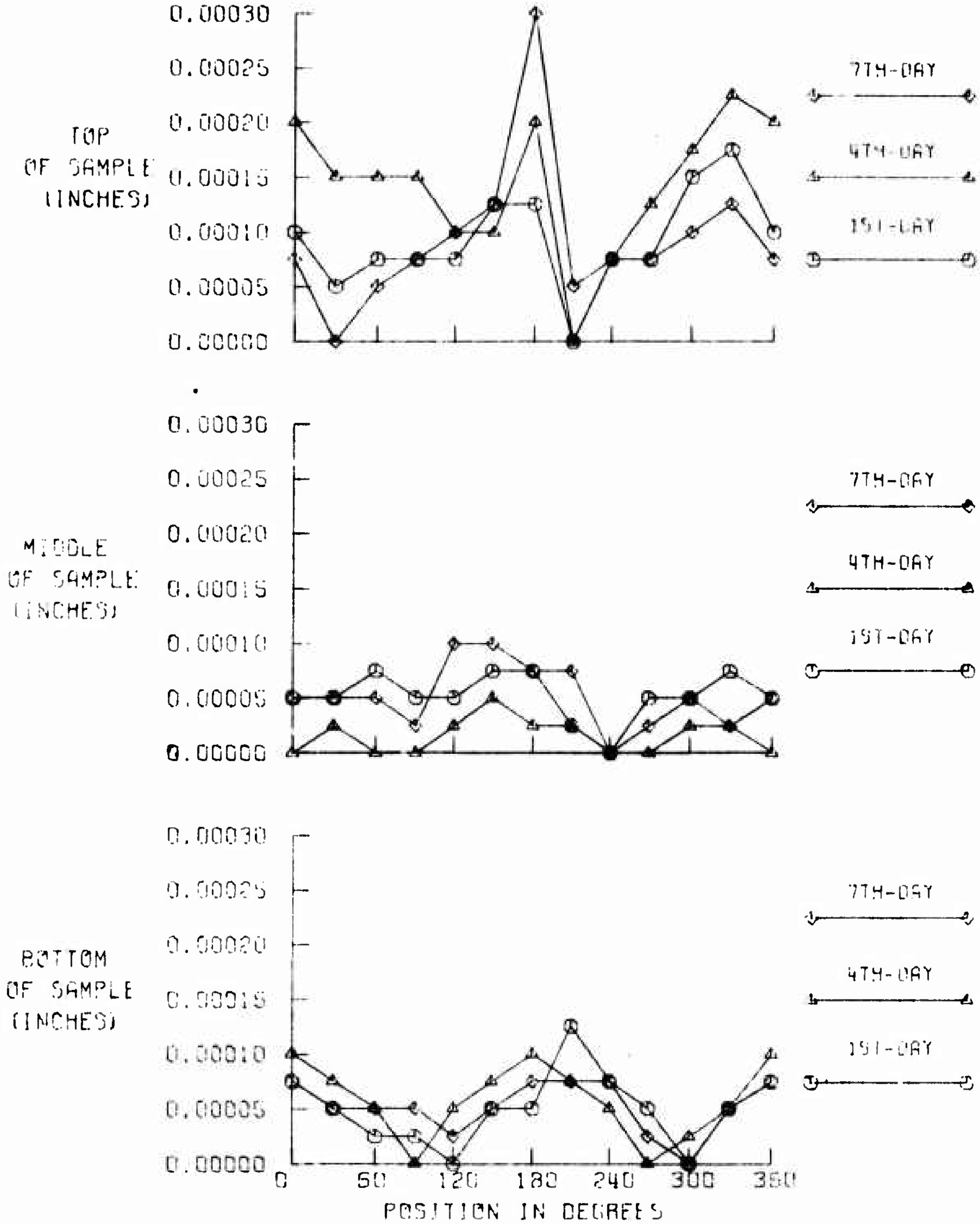


FIG. 31 : VARIATION FROM PERFECT ROUNDNESS FOR SAMPLE NUMBER 3 WOUND WITH 7 POUNDS TENSION, 1/2-INCH THICK AND CURED AT 200F FOR 4 HOURS

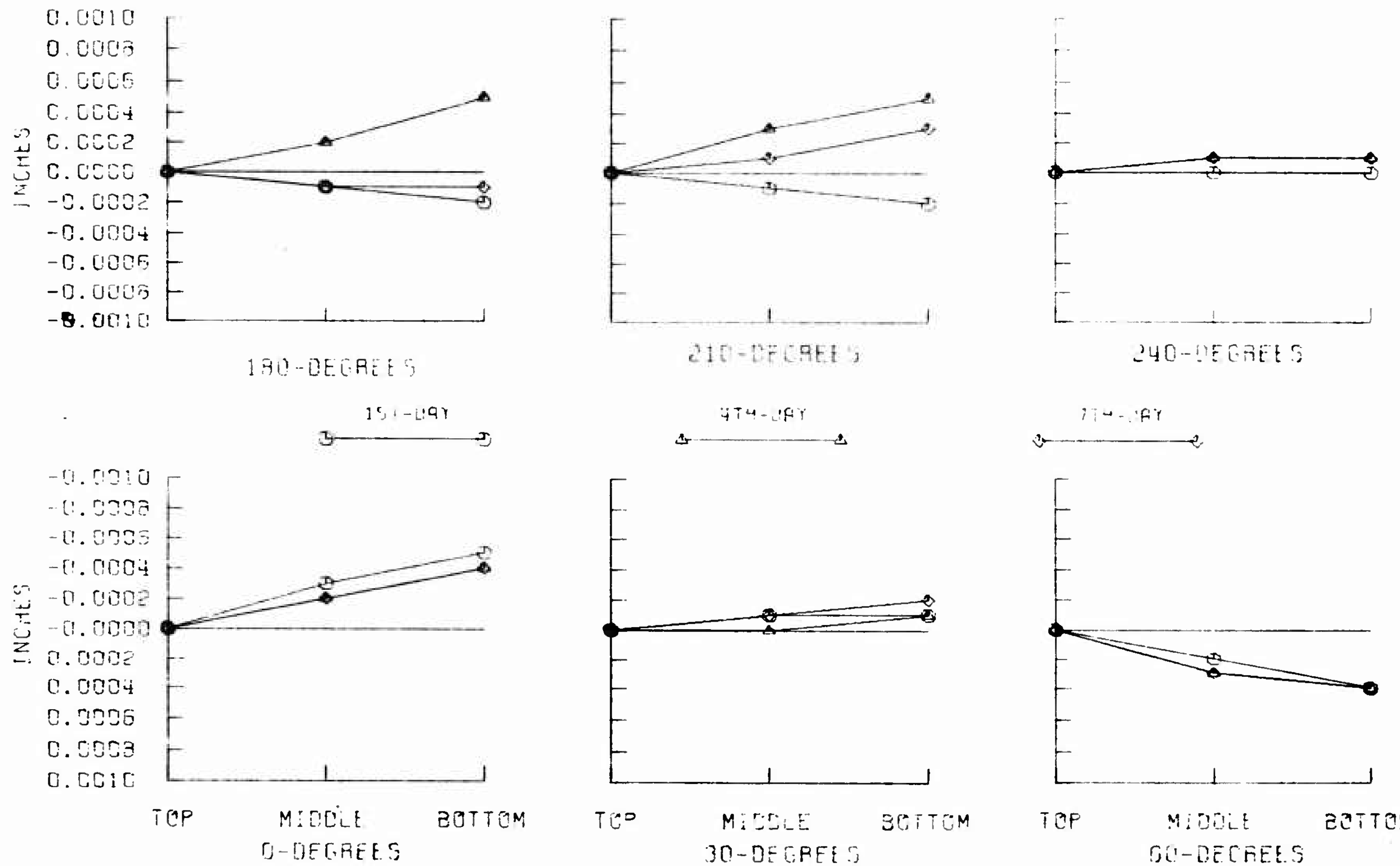


FIG. 32a. BORE TAPER FOR SAMPLE NUMBER 4 WOUND WITH 7 POUNDS TENSION, 1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

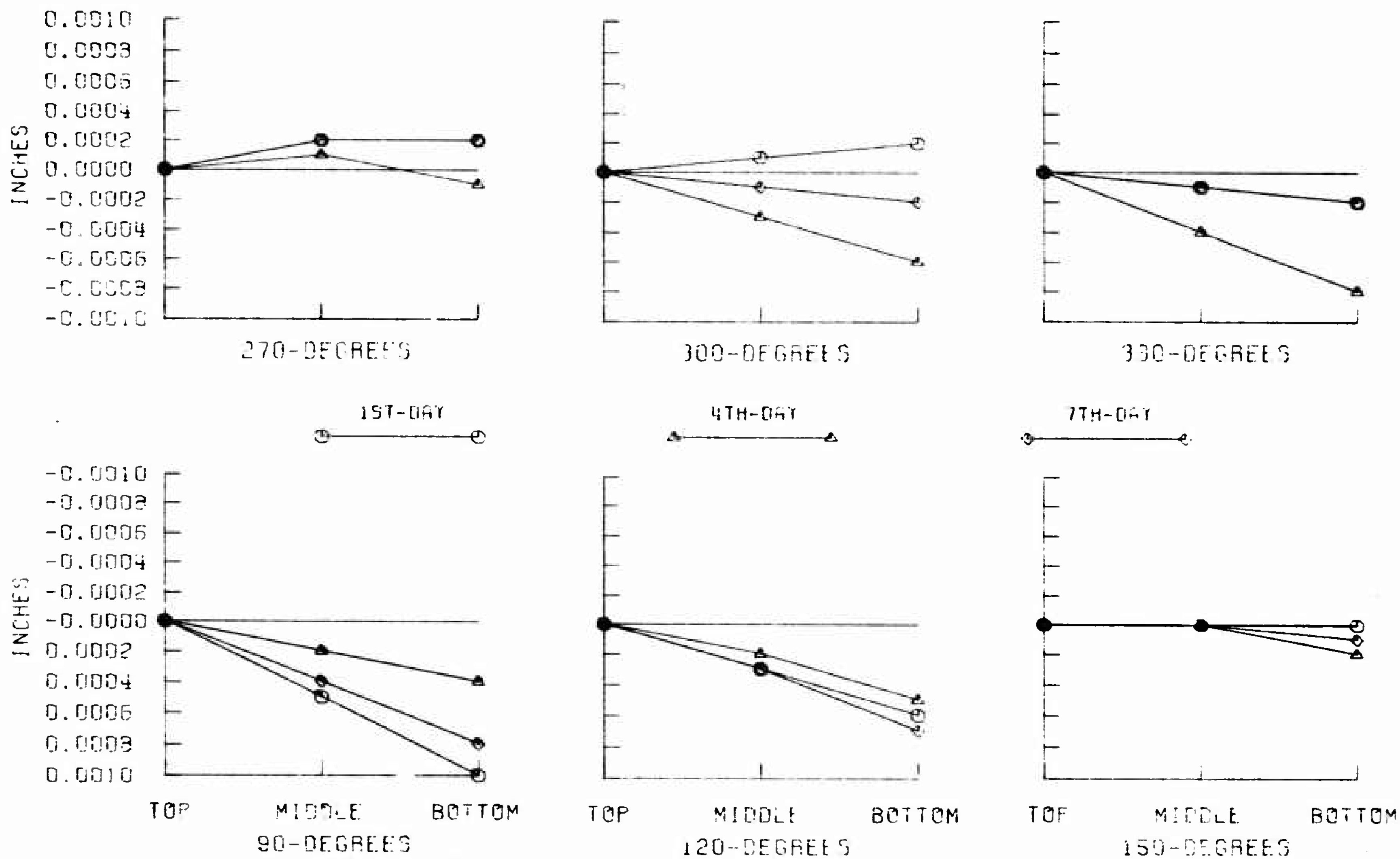


FIG. 32b . BORE TAPER FOR SAMPLE NUMBER 4 WOUND WITH 7 POUNDS TENSION, 1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

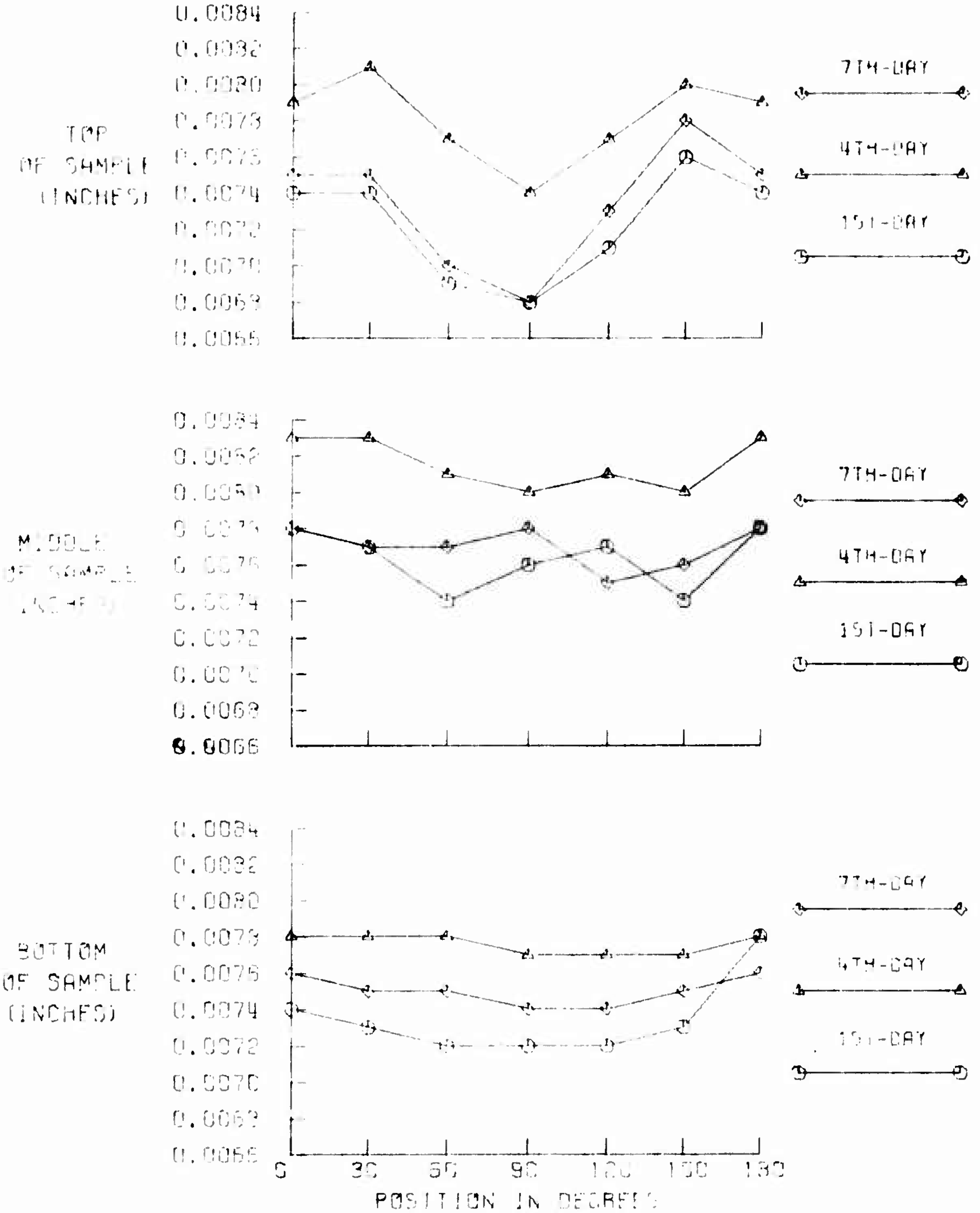


FIG. 33 : DIAMETRICAL VARIATION FROM THE NOMINAL SIZE OF 3.6872 INCHES FOR SAMPLE NUMBER 7 WOUND WITH 1 POUNDS TENSION, 1-INCH THICK AND CURED AT 200F FOR 4 HOURS

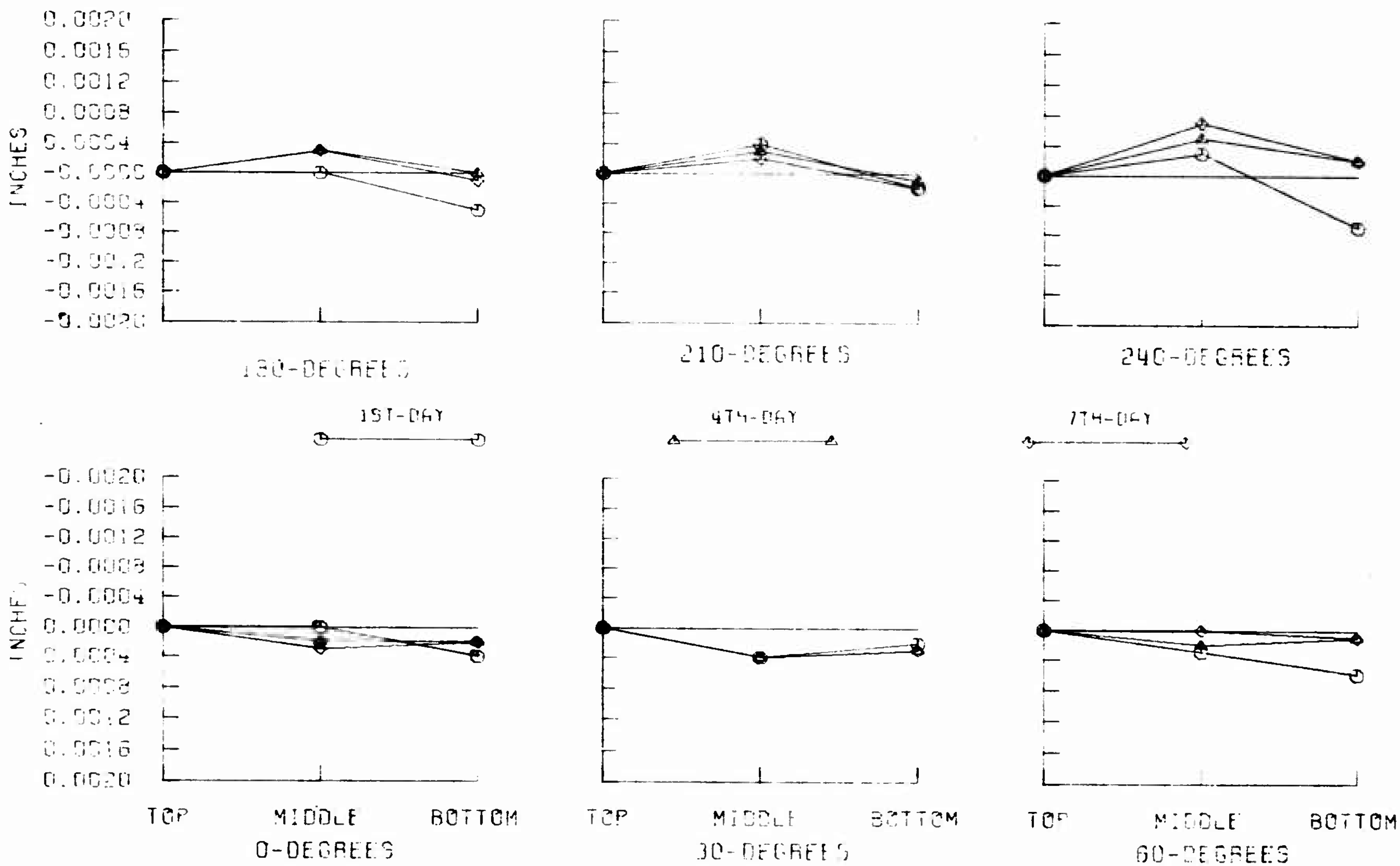


FIG. 34a. BORE TAPER FOR SAMPLE NUMBER 7 WOUND WITH 1 POUND TENSION, 1-INCH THICK AND CURED AT 200F FOR 4 HOURS

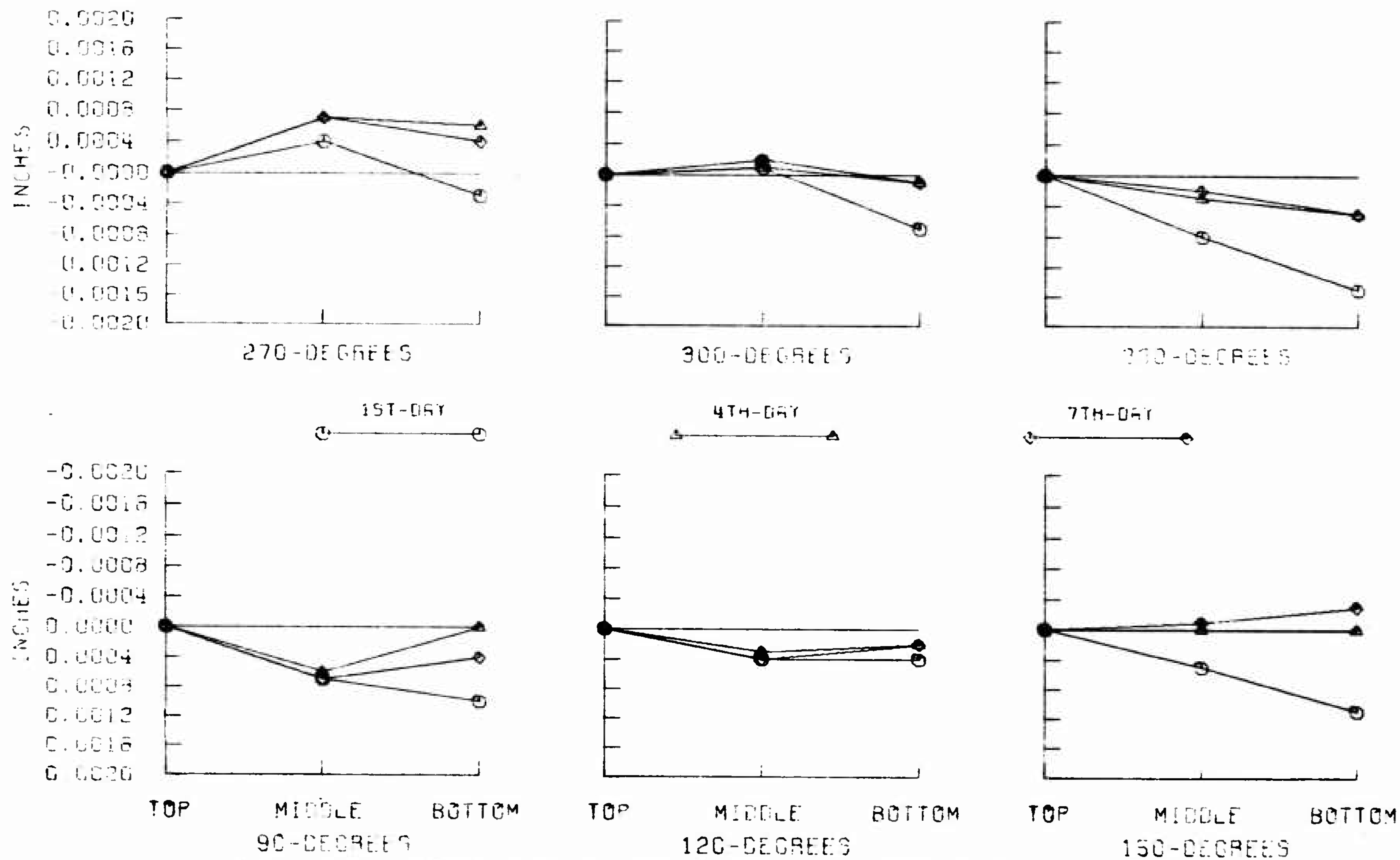


FIG. 34b . BORE TAPER FOR SAMPLE NUMBER 7 WOUND WITH 1 POUND TENSION, 1-INCH THICK AND CURED AT 200F FOR 4 HOURS

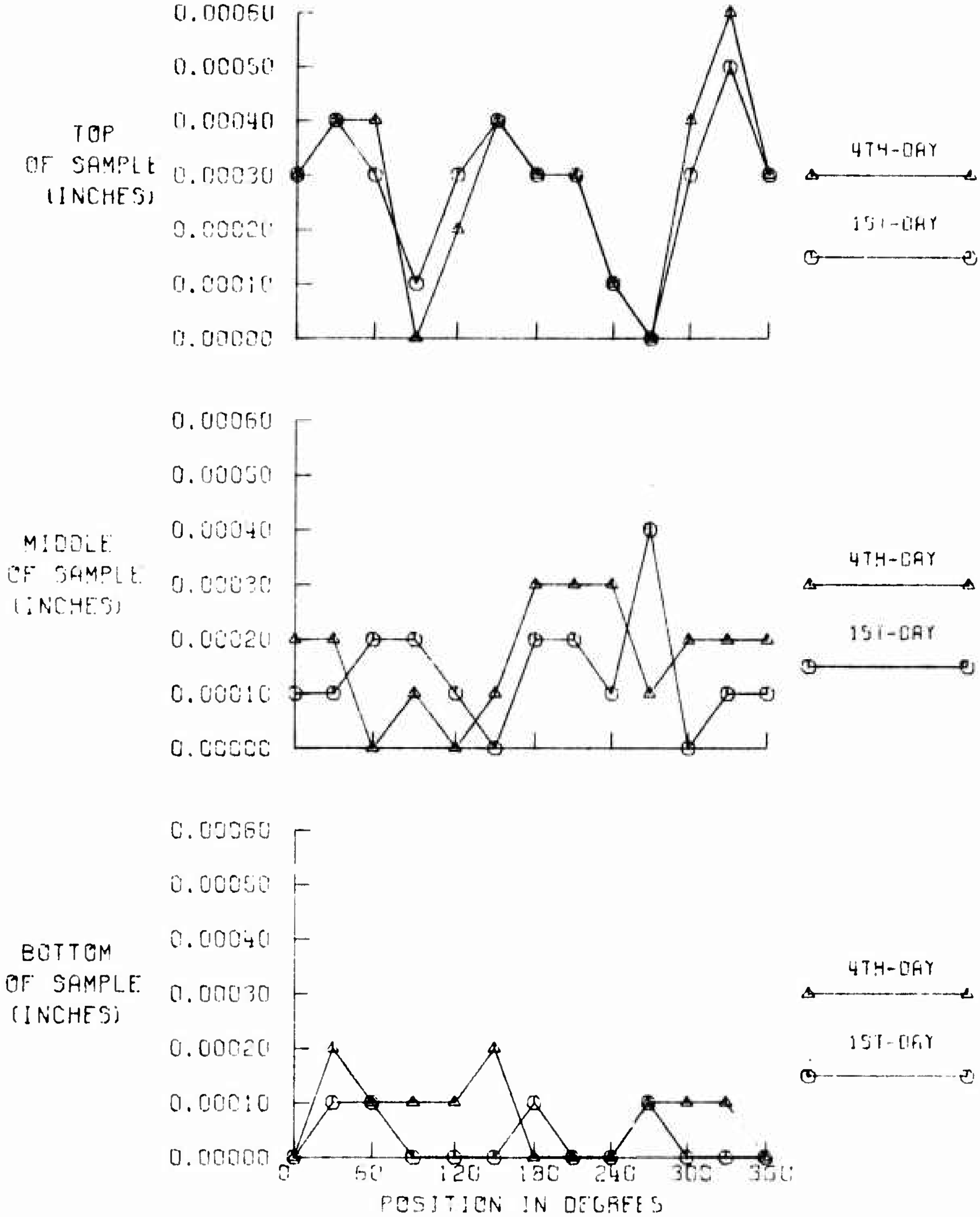


FIG. 35 VARIATION FROM PERFECT ROUNDNESS FOR SAMPLE NUMBER 7 WOUND WITH 1 POUND TENSION, 1-INCH THICK AND CURED AT 200F FOR 4 HOURS

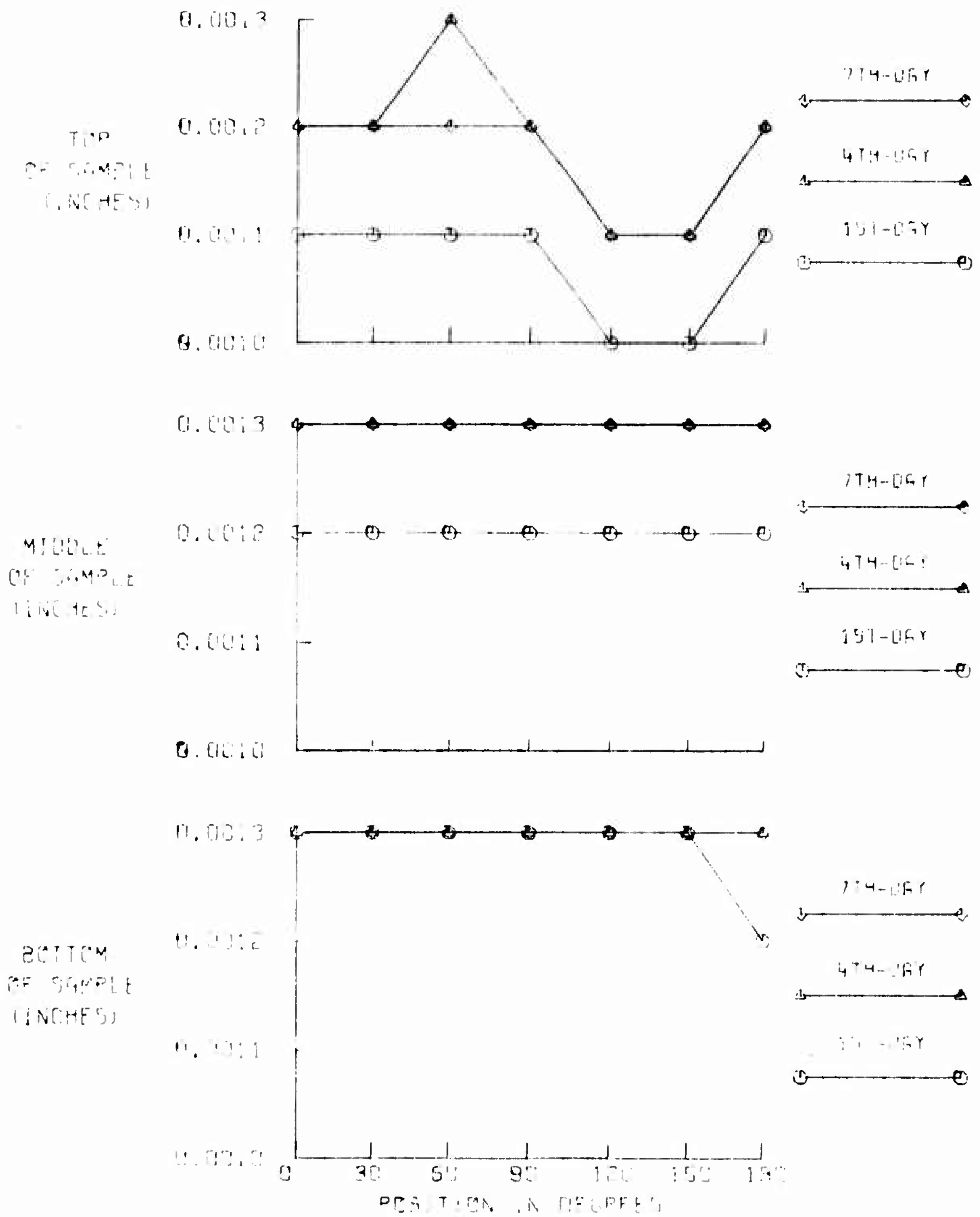


FIG. 36 DIAMETRICAL VARIATION FROM THE NOMINAL SIZE OF 3.6872 INCHES FOR SAMPLE NUMBER 3 WOUND WITH 1 POUND TENSION, 1-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

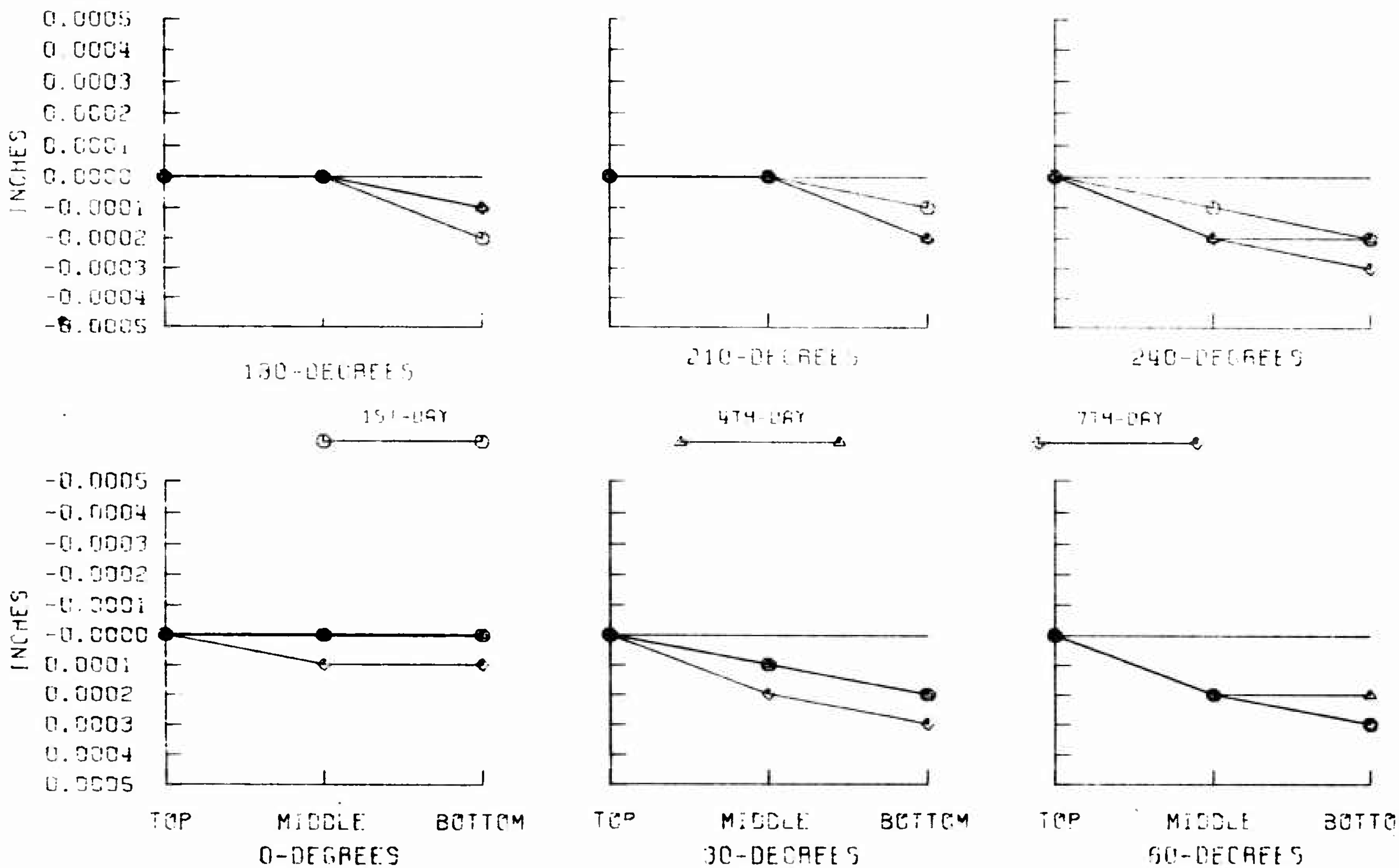


FIG. 37a : BORE TAPER FOR SAMPLE NUMBER 8 WOUND WITH 1 POUND TENSION, 1-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

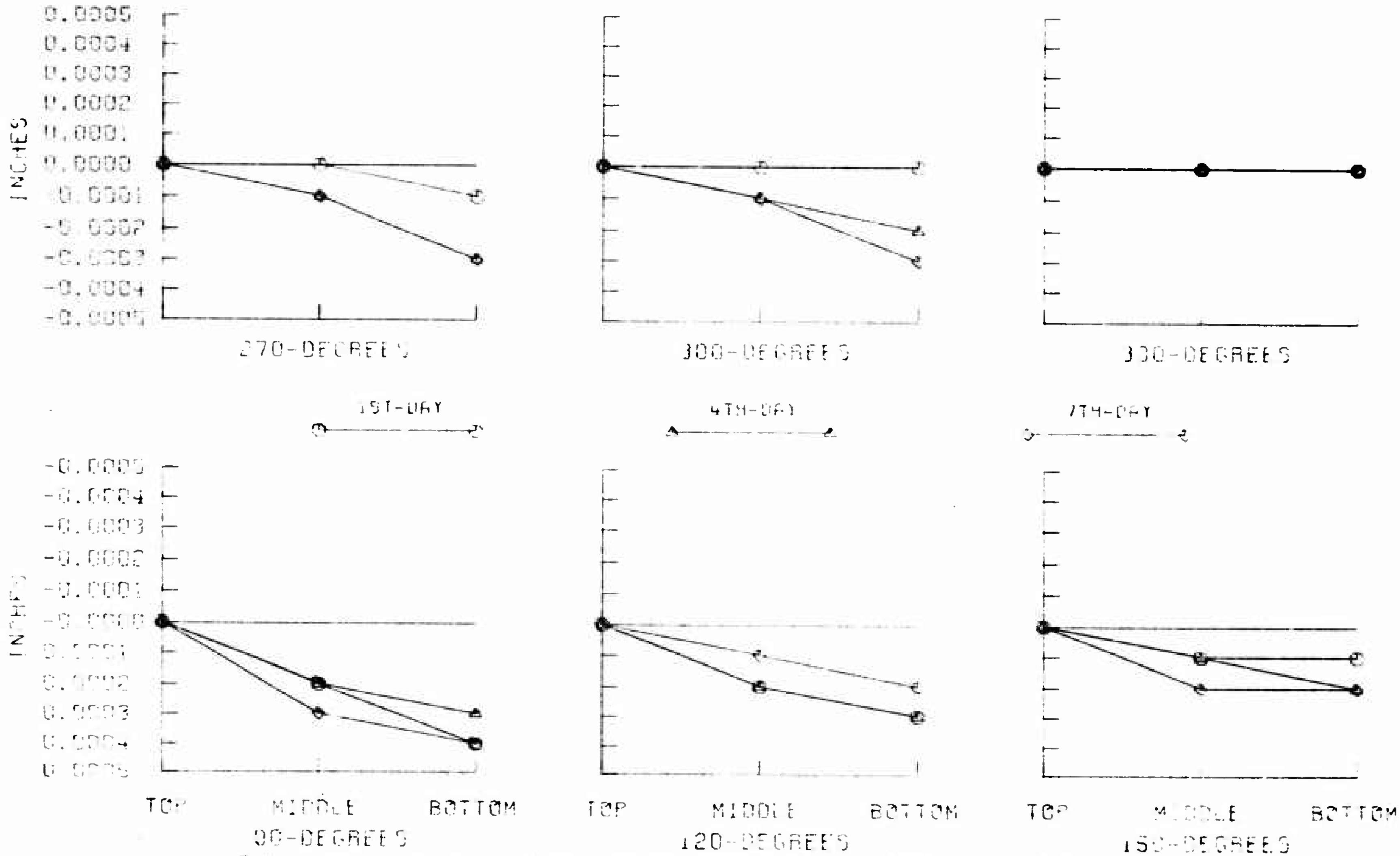


FIG. 37b BORE TAPER FOR SAMPLE NUMBER 8 WOUND WITH 1 POUND TENSION, 1-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

APPENDIX C

Reproducibility Test Data of Samples 6, 9 and 10 not included in the Main Text.

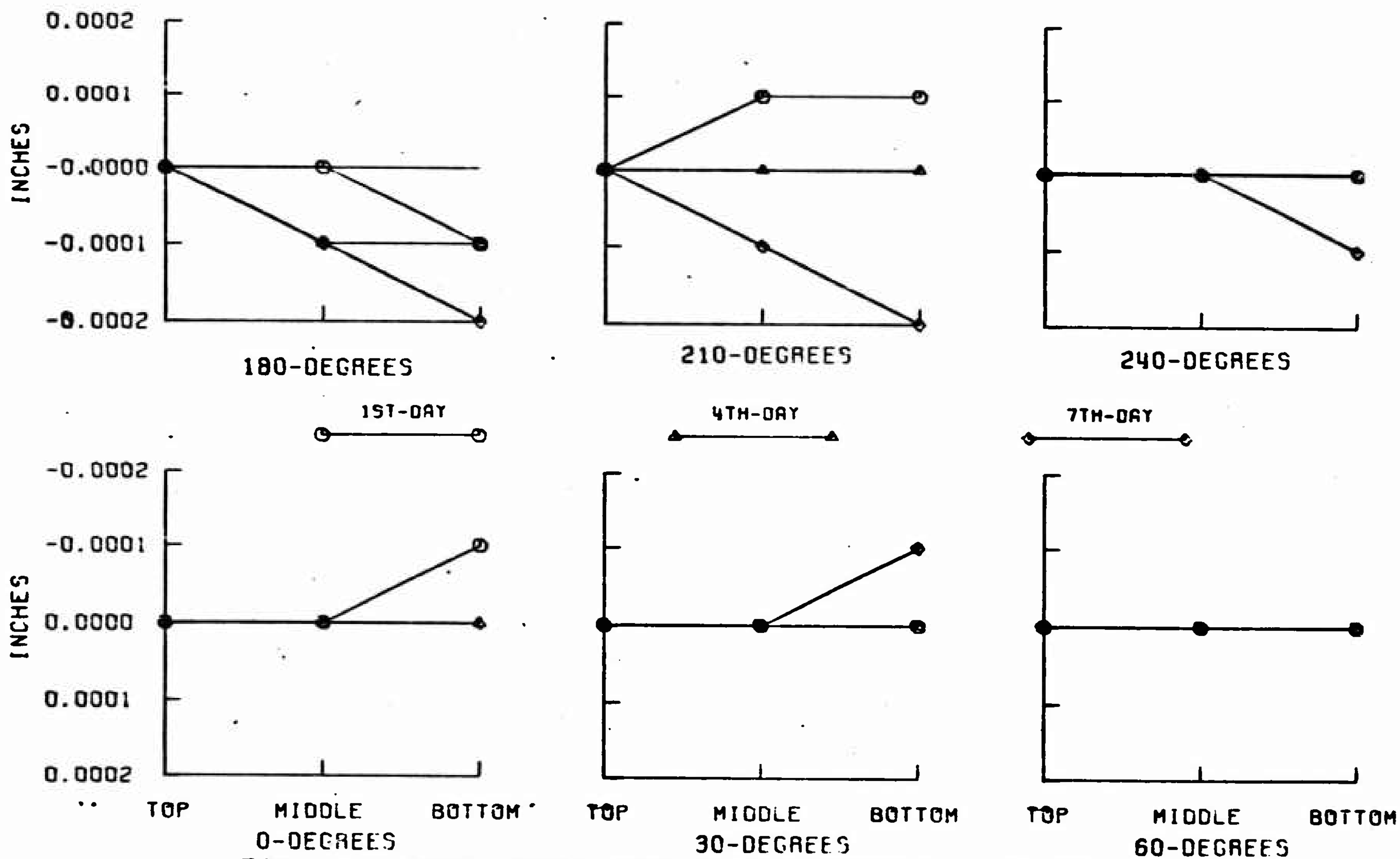


FIG. 38a: BORE TAPER FOR SAMPLE NUMBER 6 WOUND WITH 1 POUND TENSION.1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

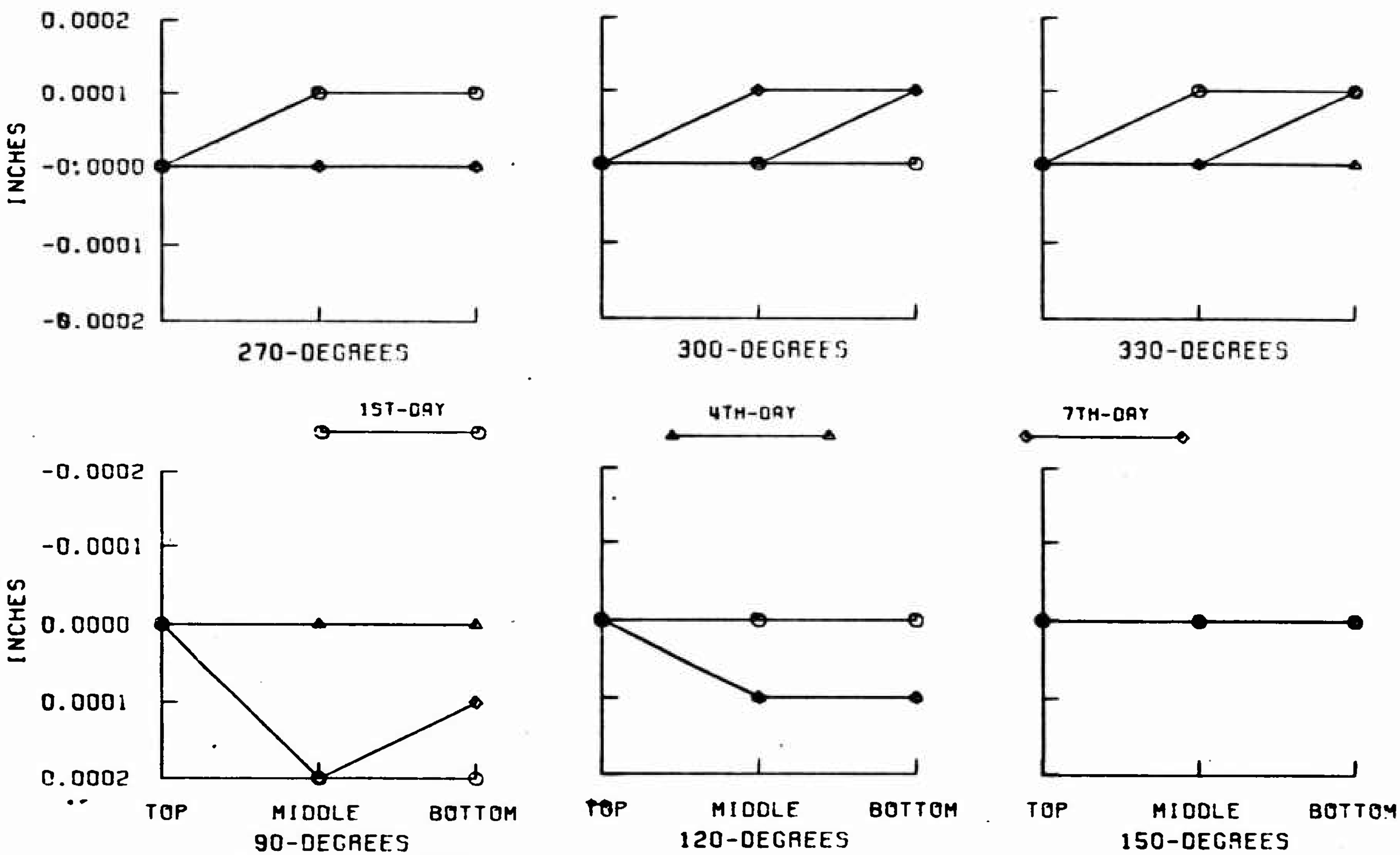


FIG. 38b: BORE TAPER FOR SAMPLE NUMBER 6 WOUND WITH 1 POUND TENSION, 1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

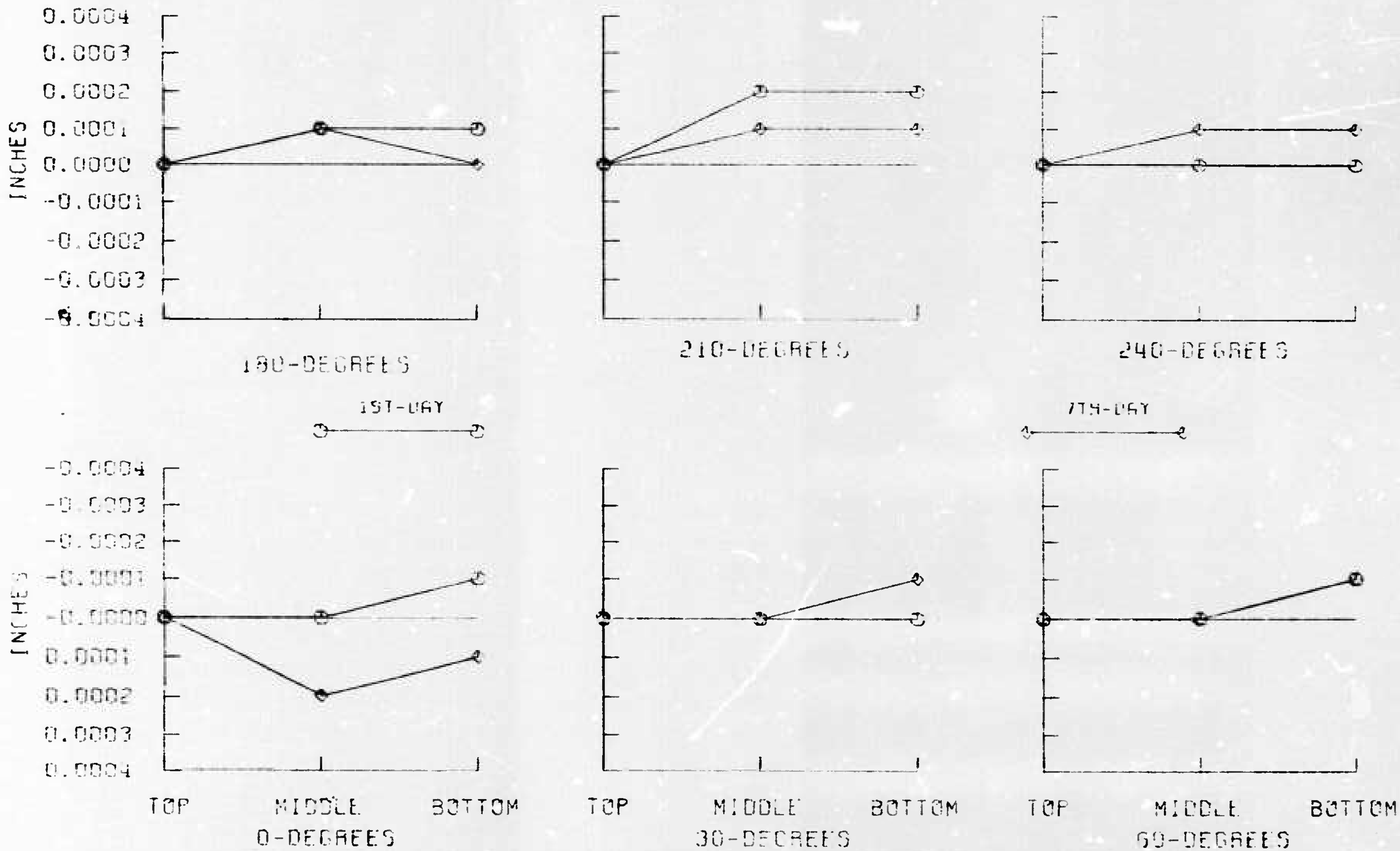


FIG. 39a BORE TAPER FOR SAMPLE NUMBER 9 WOUND WITH 1 POUND TENSION.1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

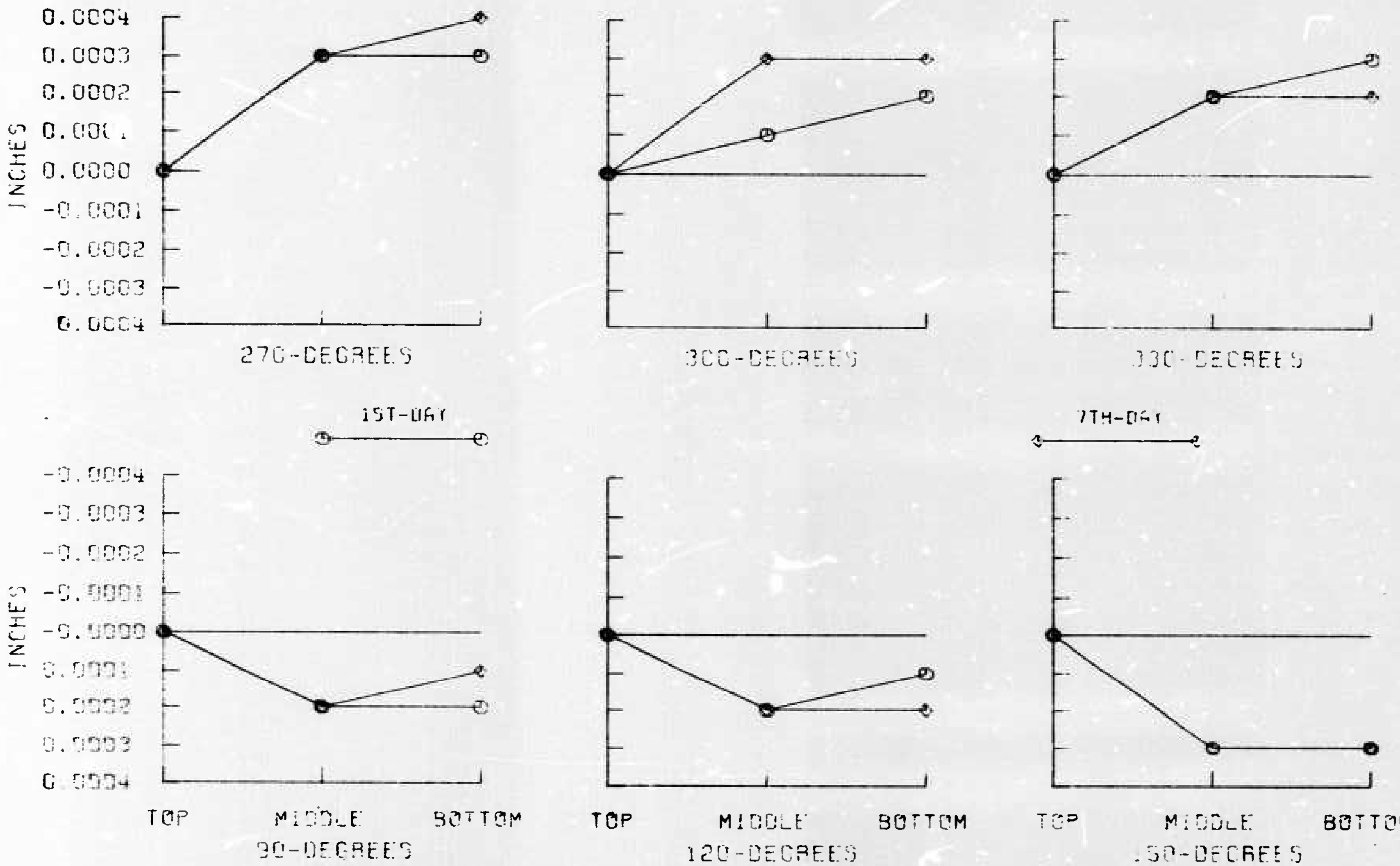


FIG. 39b. BORE TAPER FOR SAMPLE NUMBER 9 WOUND WITH 1 POUND TENSION, 1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

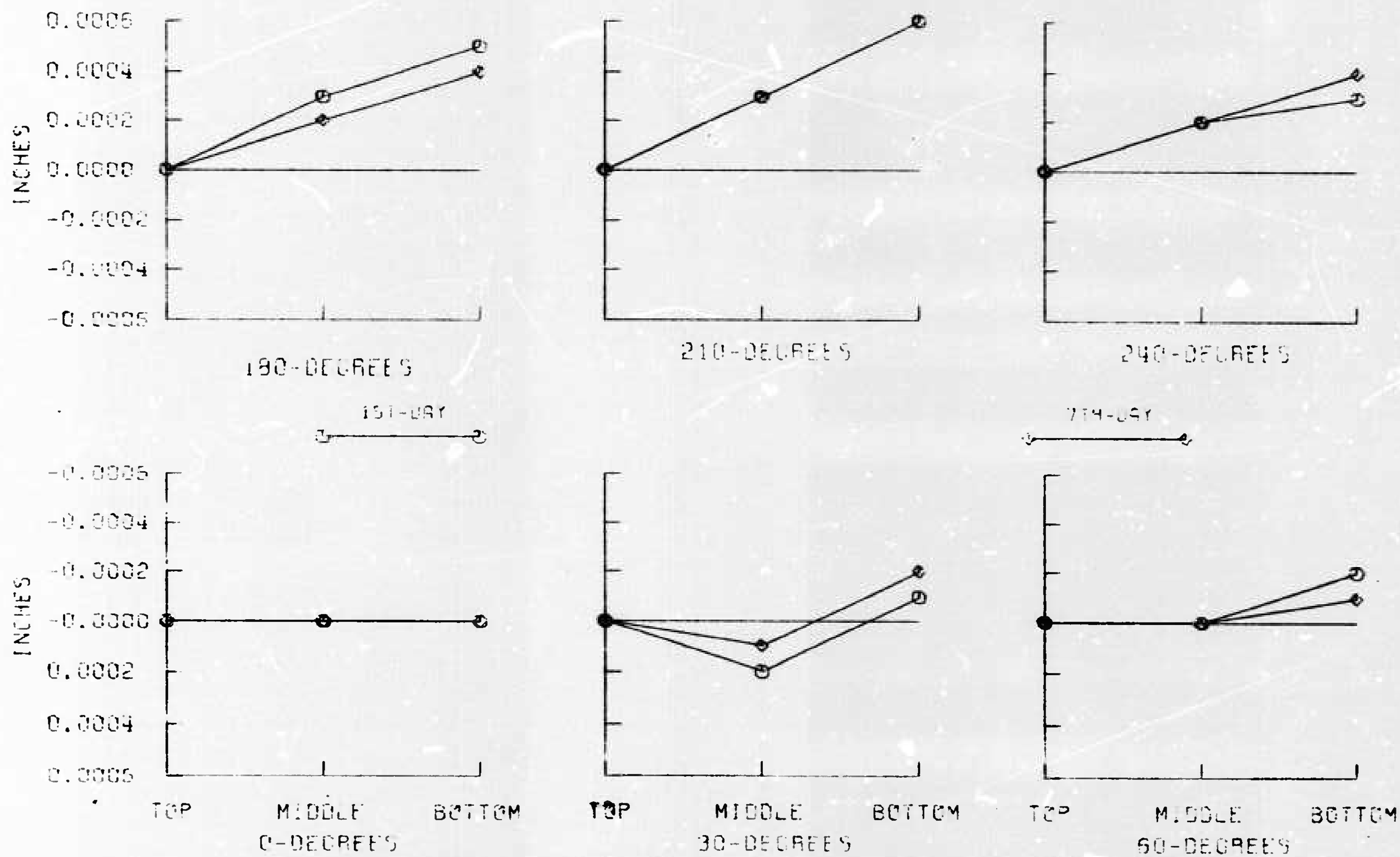


FIG 40a; BORE TAPER FOR SAMPLE NUMBER 10 WOUND WITH 1 POUND TENSION, 1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

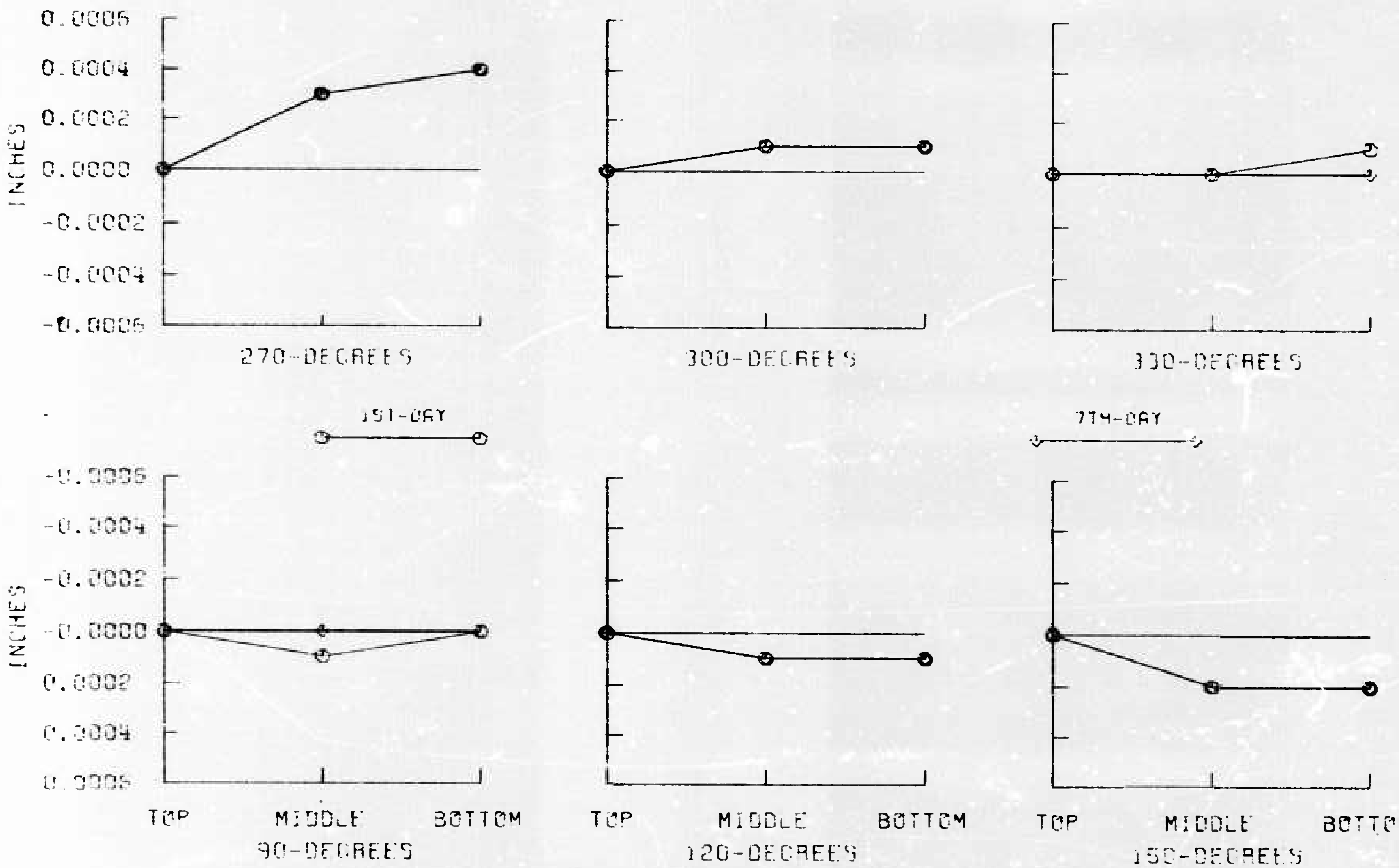


FIG.40b . BORE TAPER FOR SAMPLE NUMBER 10 WOUND WITH 1 POUND TENSION,1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS

APPENDIX D

Elevated Temperature Test Data of Samples 4 and 6 not included in the Main Text.

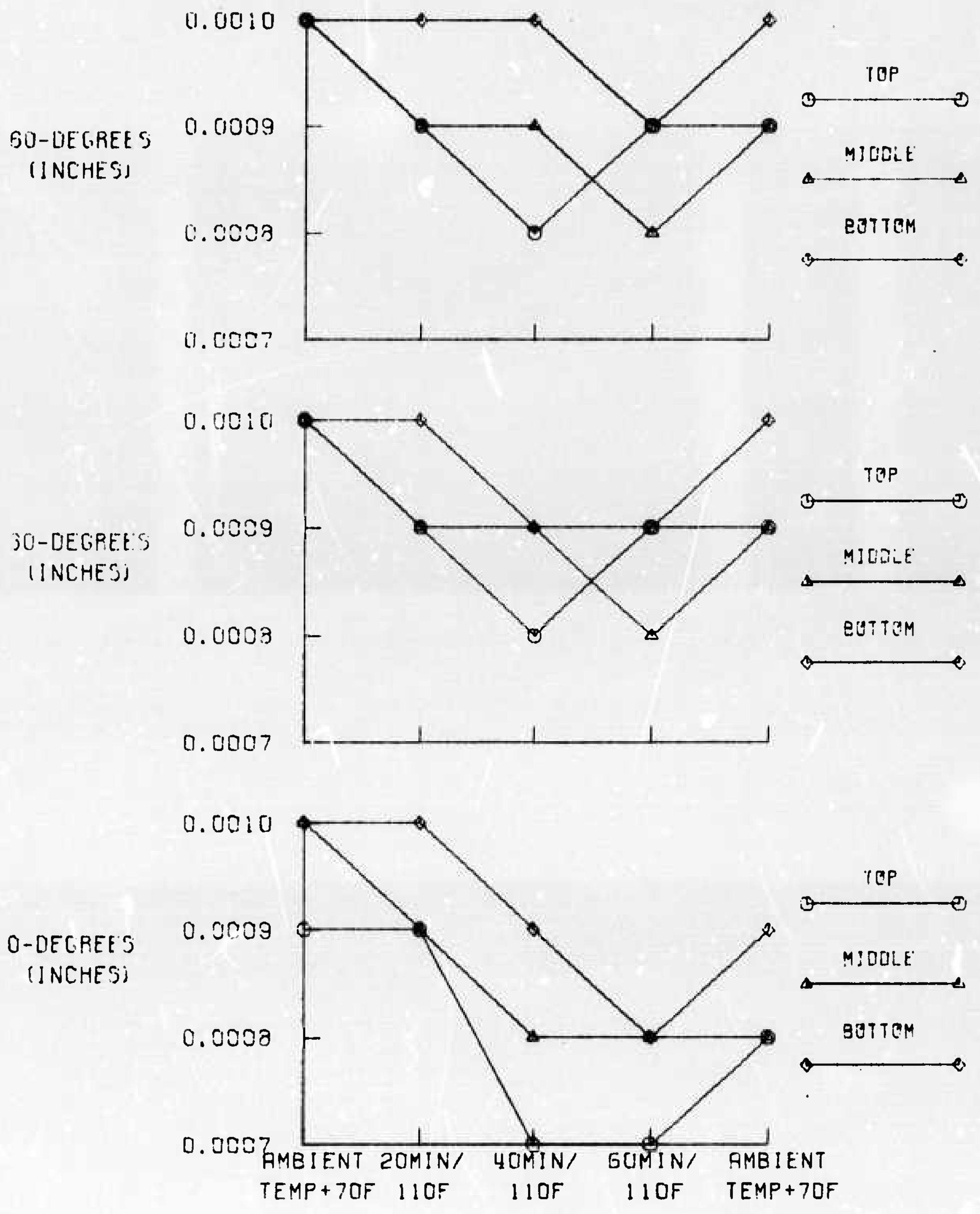


FIG. 41a : DIAMETRICAL VARIATION FROM THE NOMINAL SIZE OF 3.6872 INCHES FOR SAMPLE NUMBER 4 WOUND WITH 7 POUNDS TENSION, 1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS. SAMPLE REMAINED AT ROOM TEMPERATURE FOR 5 WEEKS AND THEN HEATED TO 110F

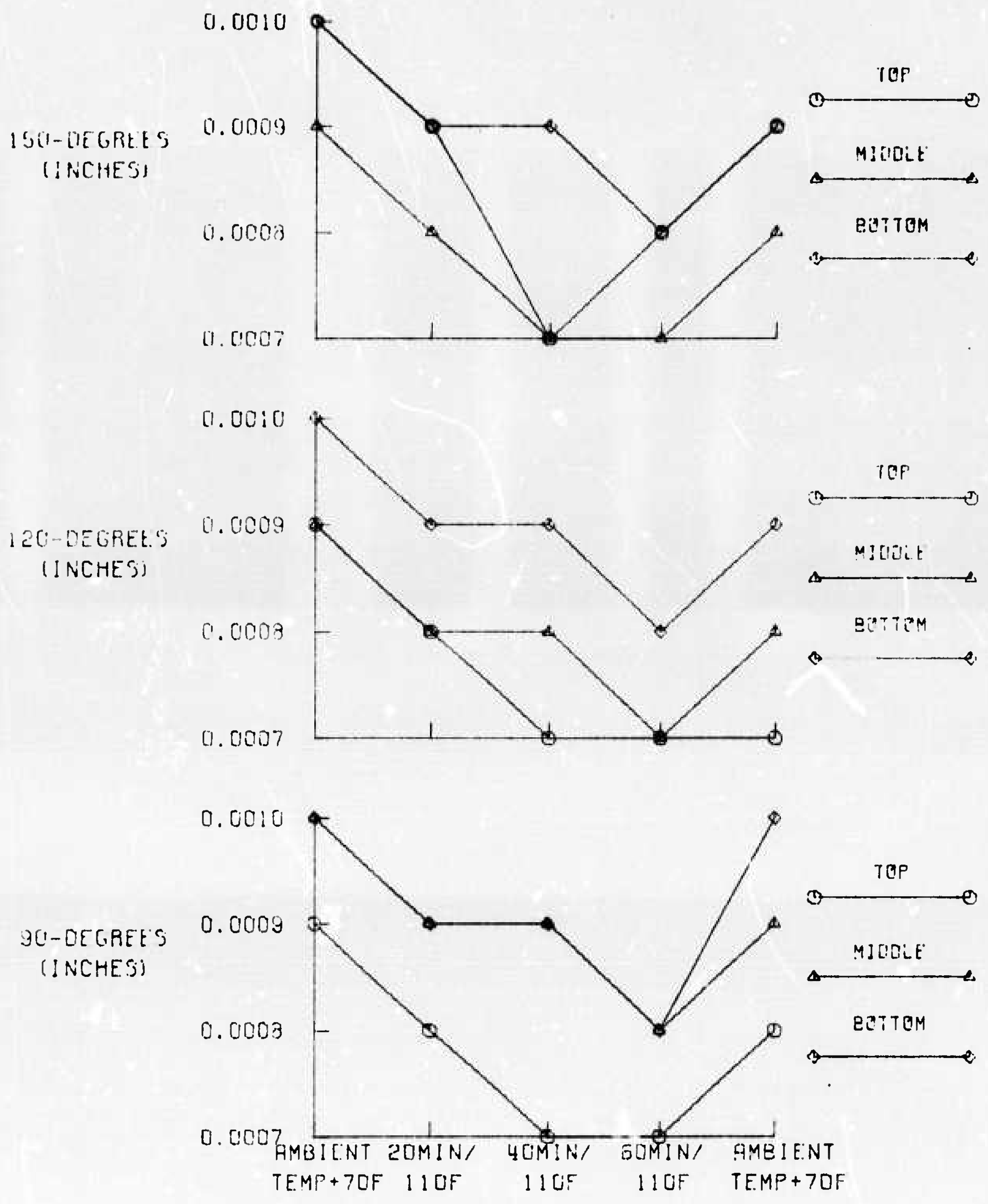


FIG. 41b: DIAMETRICAL VARIATION FROM THE NOMINAL SIZE OF 3.6872 INCHES FOR SAMPLE NUMBER 4 WOUND WITH 7 POUNDS TENSION.1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS.SAMPLE REMAINED AT ROOM TEMPERATURE FOR 5 WEEKS AND THEN HEATED TO 110F

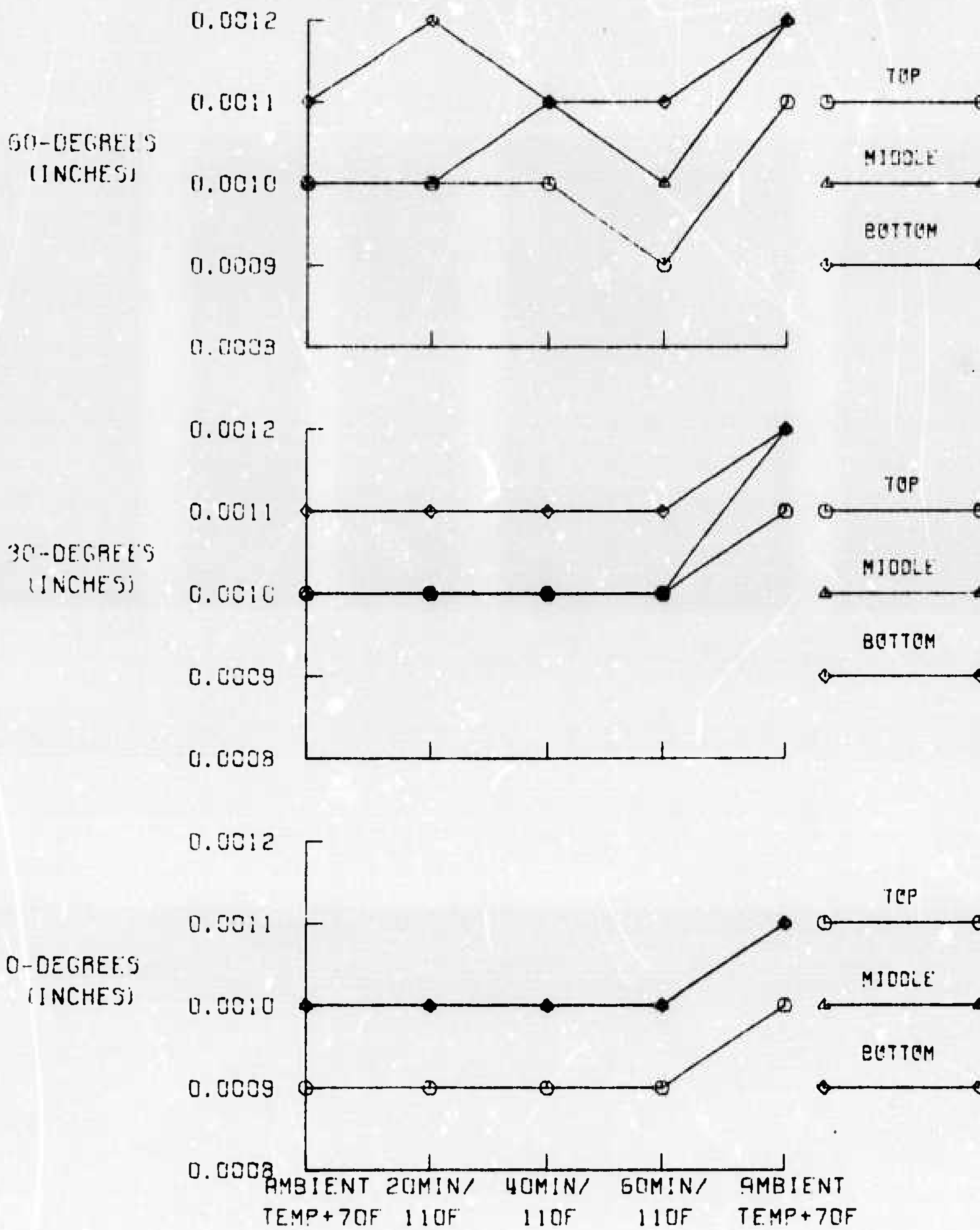


FIG.42a · DIAMETRICAL VARIATION FROM THE NOMINAL SIZE OF 3.6872 INCHES FOR SAMPLE NUMBER 4 WOUND WITH 7 POUNDS TENSION, 1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS. SAMPLE REMAINED AT ROOM TEMPERATURE FOR AN ADDITIONAL 2 WEEKS AFTER FIRST BEING HEATED TO 110F. THE SAMPLE IS AGAIN HEATED TO 110F

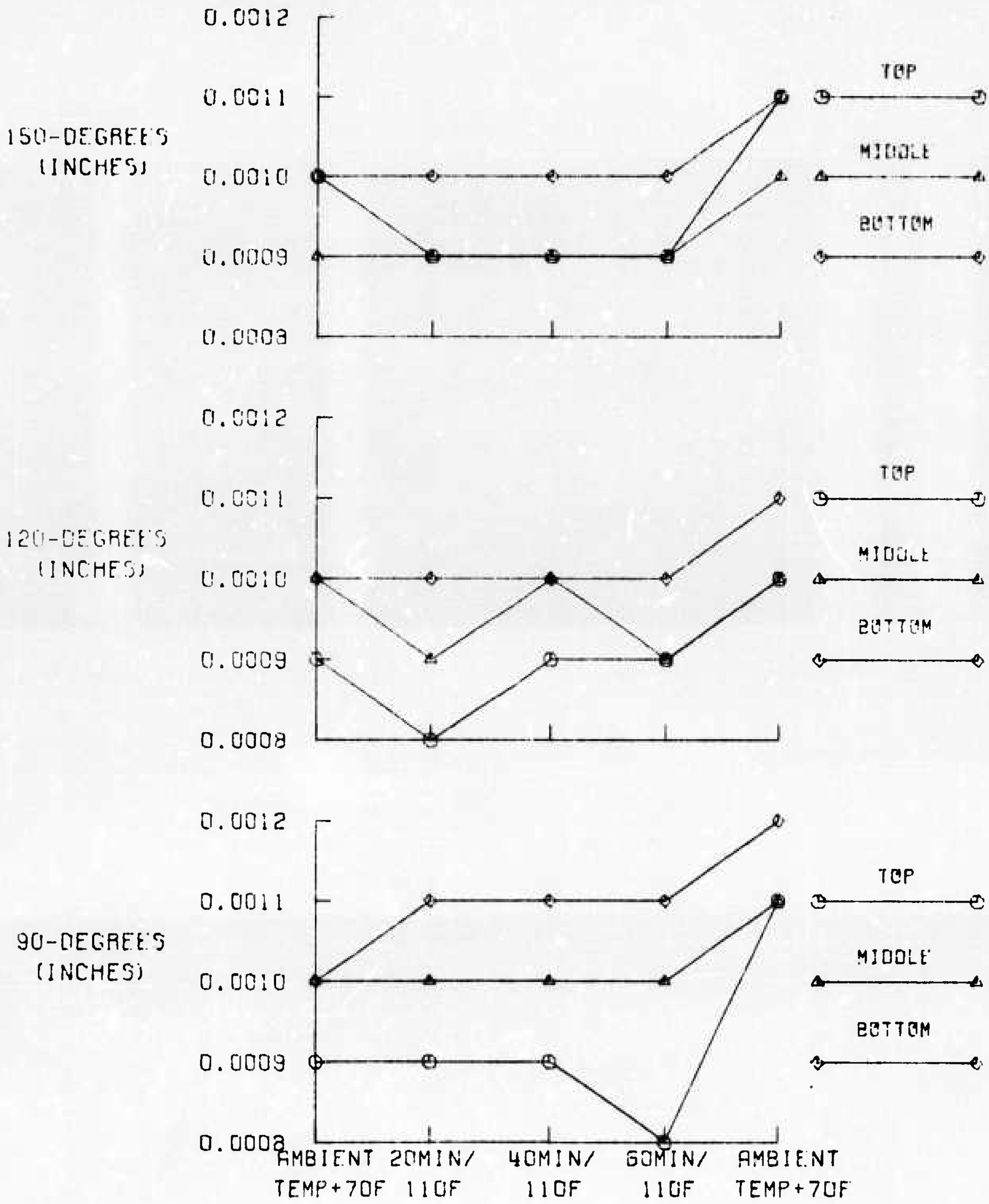


FIG.42b : DIAMETRICAL VARIATION FROM THE NOMINAL SIZE OF 3.6872 INCHES FOR SAMPLE NUMBER 4 WOUND WITH 7 POUNDS TENSION, 1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS. SAMPLE REMAINED AT ROOM TEMPERATURE FOR AN ADDITIONAL 2 WEEKS AFTER FIRST BEING HEATED TO 110F. THE SAMPLE IS AGAIN HEATED TO 110F

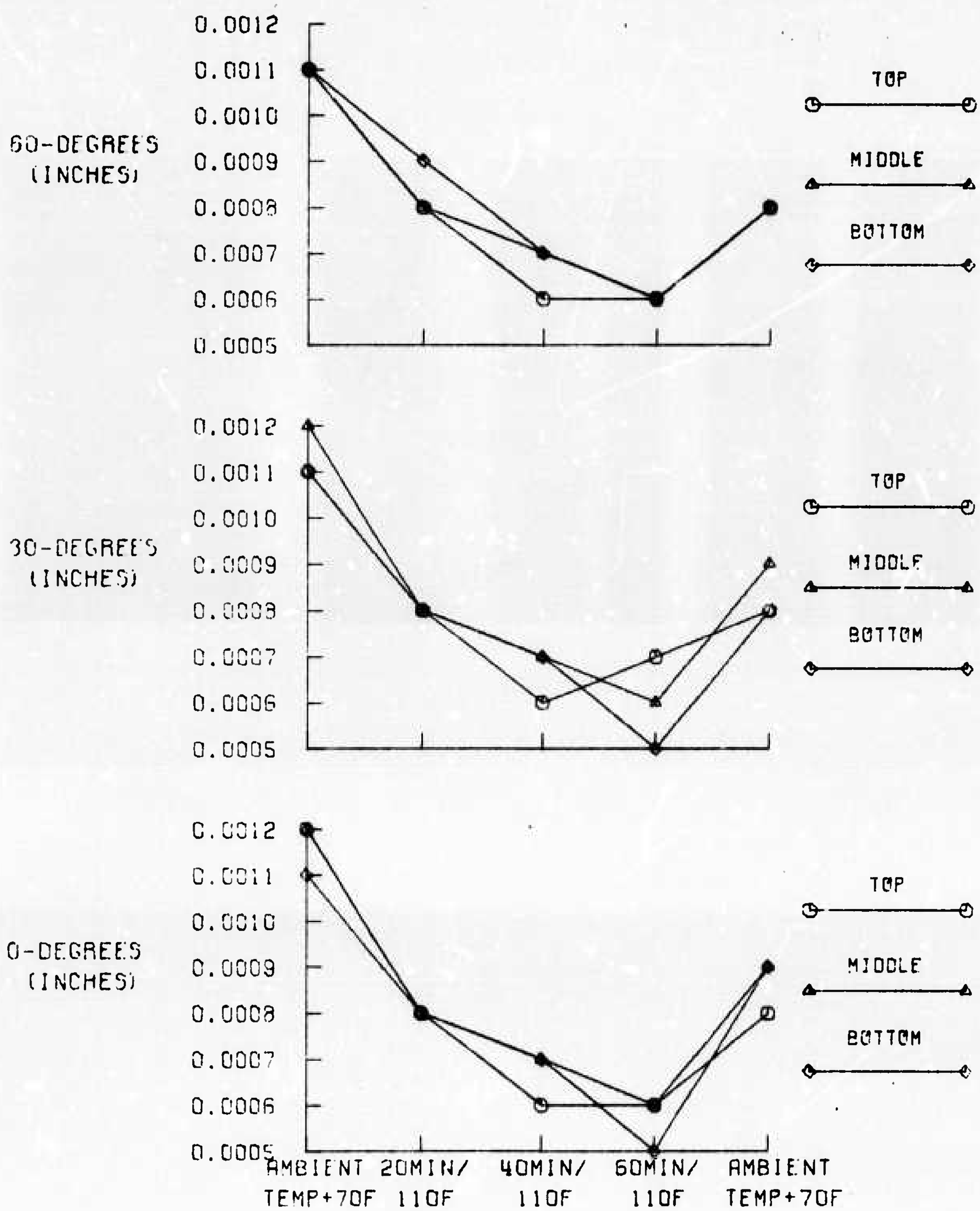


FIG. 43a : DIAMETRICAL VARIATION FROM THE NOMINAL SIZE OF 3.6872 INCHES FOR SAMPLE NUMBER 6 WOUND WITH 1 POUND TENSION.1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS.SAMPLE REMAINED AT ROOM TEMPERATURE FOR 4 WEEKS AND THEN HEATED TO 110F

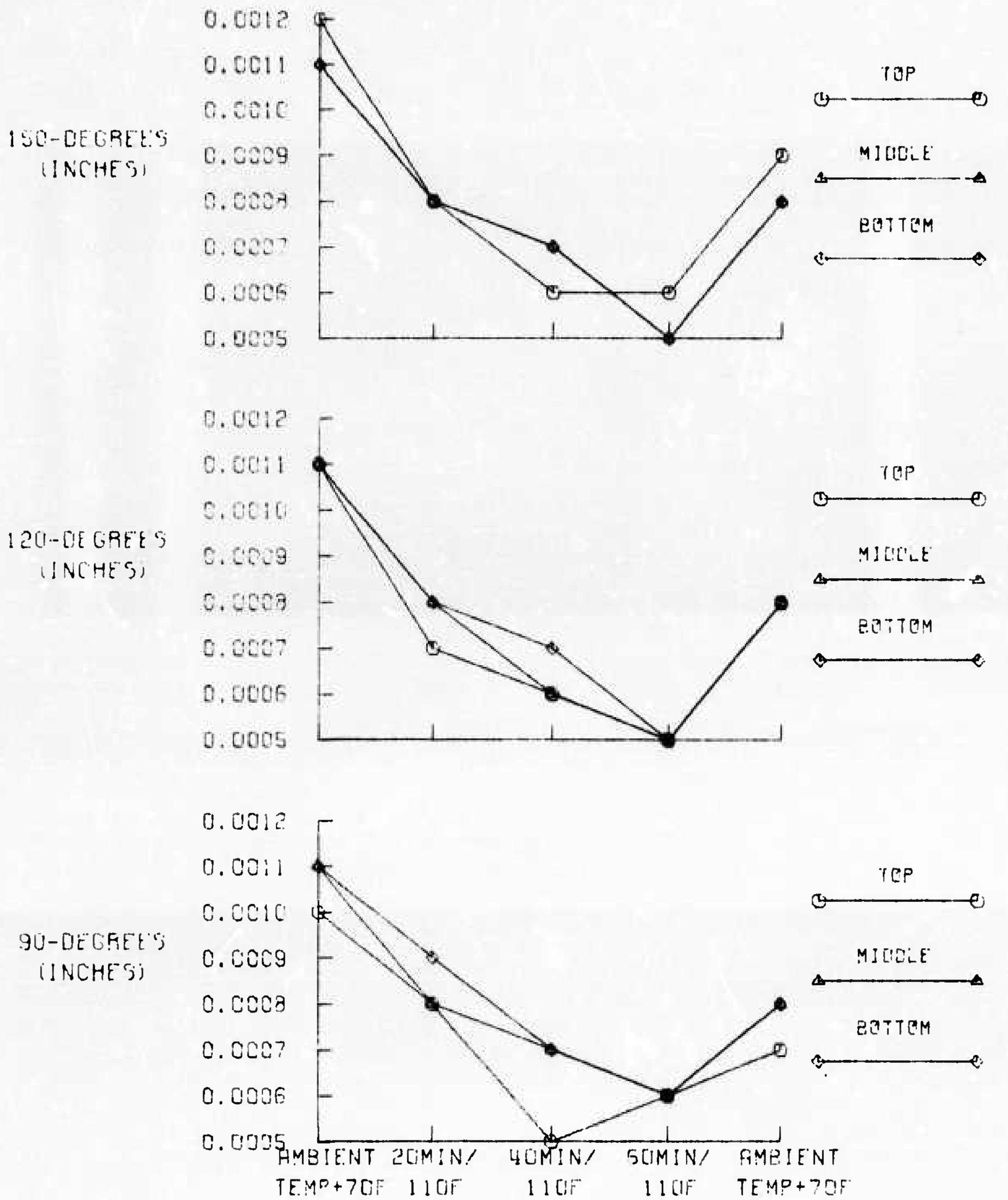


FIG. 43b: DIAMETRICAL VARIATION FROM THE NOMINAL SIZE OF 3.6872 INCHES FOR SAMPLE NUMBER 6 WOUND WITH 1 POUND TENSION.1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS.SAMPLE REMAINED AT ROOM TEMPERATURE FOR 4 WEEKS AND THEN HEATED TO 110F

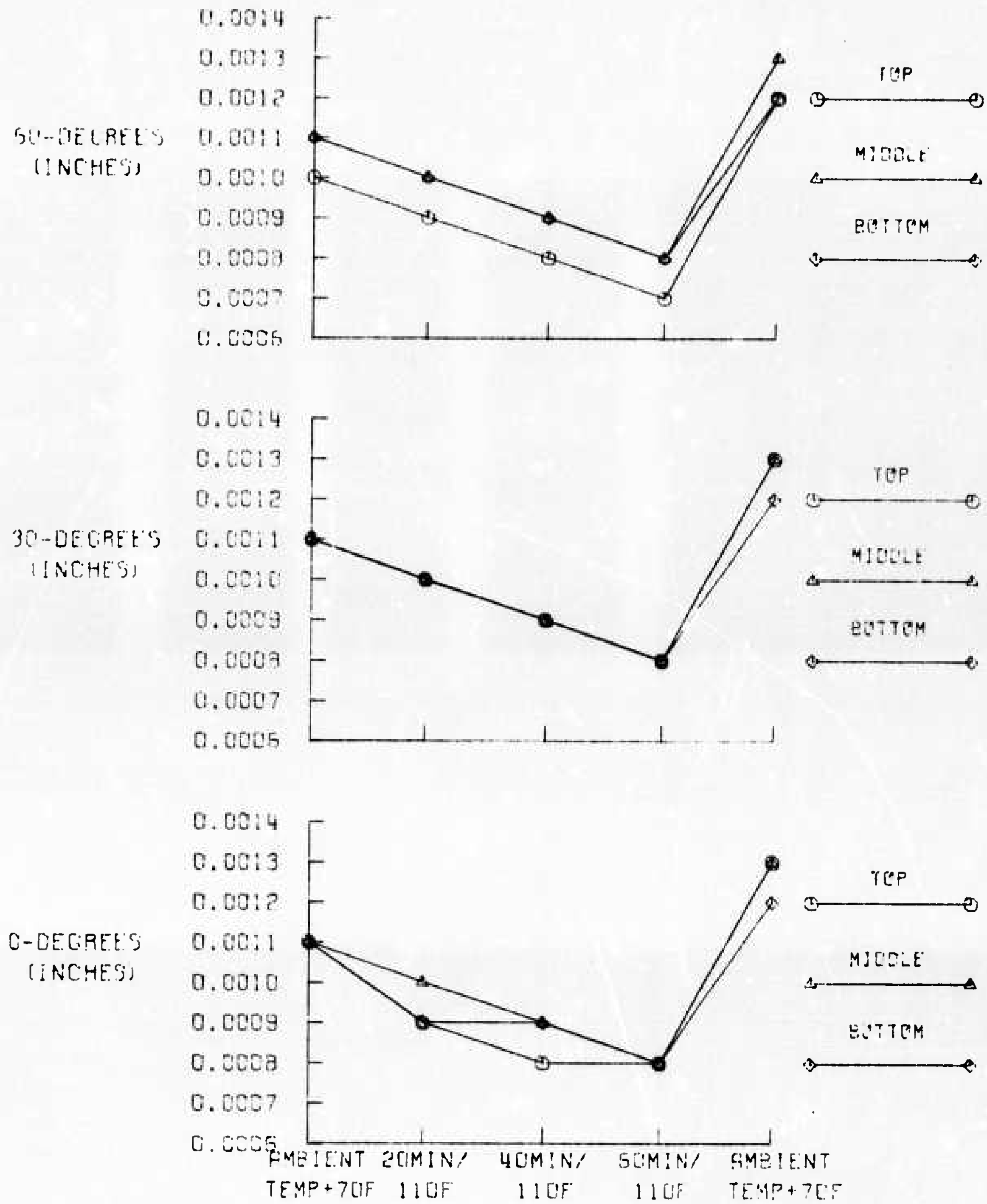


FIG. 44a DIAMETRICAL VARIATION FROM THE NOMINAL SIZE OF 3.6872 INCHES FOR SAMPLE NUMBER 6 WOUND WITH 1 POUND TENSION, 1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS. SAMPLE REMAINED AT ROOM TEMPERATURE FOR AN ADDITIONAL 2 WEEKS AFTER FIRST BEING HEATED TO 110F. THE SAMPLE IS AGAIN HEATED TO 110F

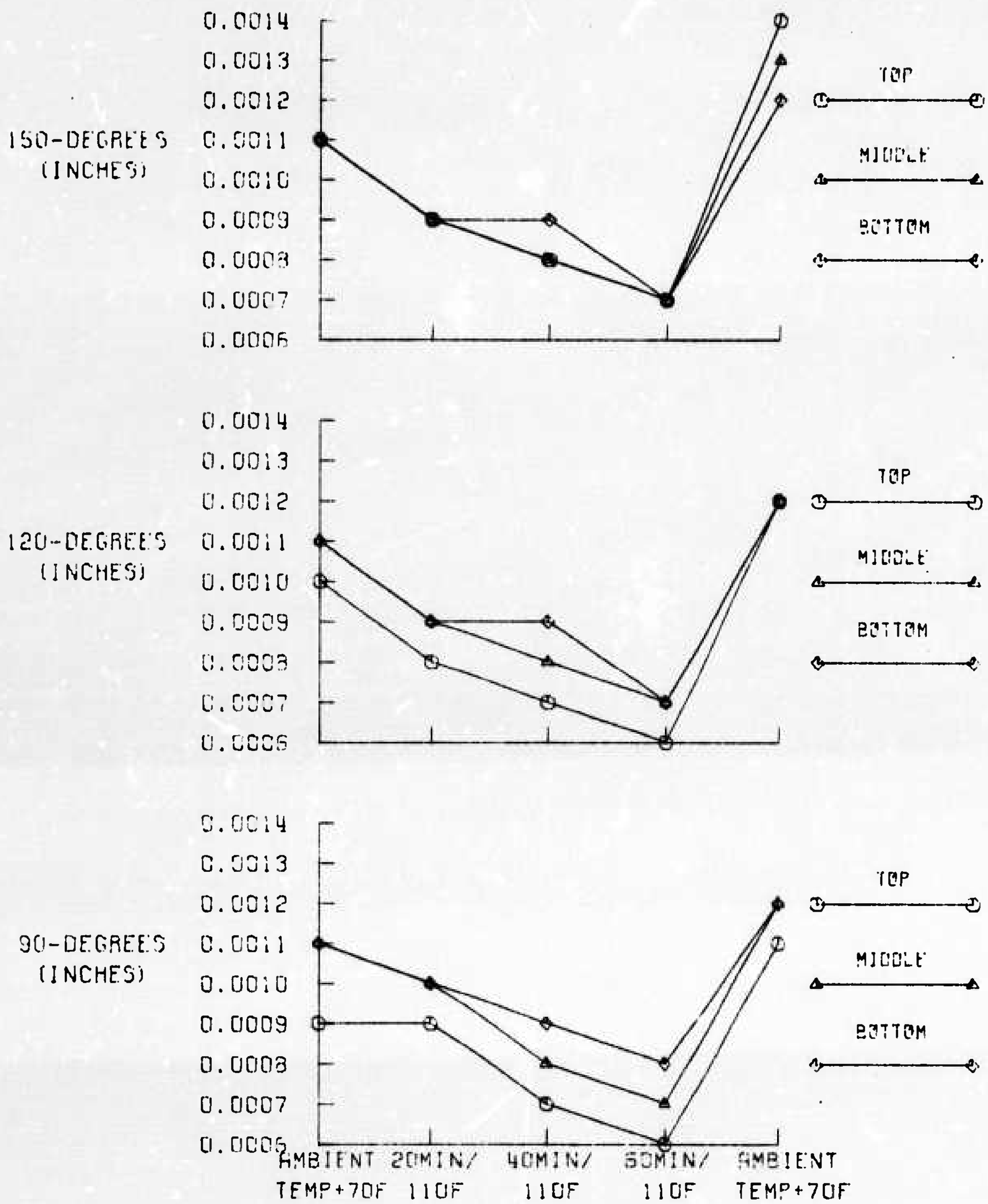


FIG.44b · DIAMETRICAL VARIATION FROM THE NOMINAL SIZE OF 3.6872 INCHES FOR SAMPLE NUMBER 6 WOUND WITH 1 POUND TENSION, 1/2-INCH THICK AND CURED AT ROOM TEMPERATURE FOR 48 HOURS. SAMPLE REMAINED AT ROOM TEMPERATURE FOR AN ADDITIONAL 2 WEEKS AFTER FIRST BEING HEATED TO 110F. THE SAMPLE IS AGAIN HEATED TO 110F